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Original Article

Anatomy Section

Medial Cerebral Sulci Variability for Surgical Corridors: A Scoping Review of Cadaveric Evidence

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ABSTRACT

Introduction: Medial sulci are key intraoperative landmarks and radiologic boundaries that determine safe interhemispheric approaches and accurate Magnetic Resonance Imaging (MRI) interpretations. The cingulate, paracingulate, calcarine, parieto-occipital, callosal, rostral, supra-rostral, and subparietal sulci are the principal surgical corridors and radiologic boundaries on the medial surface. These structures serve as essential neuroanatomical landmarks and surgical corridors in micro neurosurgical procedures; however, they exhibit considerable morphological variability. This scoping review consolidates cadaveric morphology and morphometry to define reliable versus variable medial sulcal features that guide surgical corridors and radiologic localisation.

Aim: To synthesise cadaveric morphological and morphometric data on the medial cerebral sulci and determine which sulci demonstrate consistent versus variable anatomical patterns.

Materials and Methods: In the present scoping review, the comprehensive literature search identified 4,440 records in total. After applying the eligibility criteria of the original cadaveric anatomical studies that described the morphology and/or morphometry of the cingulate, paracingulate, calcarine, parieto-occipital, and subparietal sulci in the human brain, a total of eight cadaveric studies were included. Data were extracted on sample characteristics, morphological classification, and quantitative morphometry of the medial cerebral sulci.

Results: A total of 8 cadeveric studies met the inclusion criteria collectively examining 422 hemispheres.Across 422 hemispheres, the cingulate sulcus was consistent, whereas the paracingulate sulcus was variable in shape. The present study mapped sulcal configurations to interhemispheric approach planning. The calcarine sulcus demonstrated relatively stable morphometry, with mean anterior and posterior segment lengths of 23-35 mm. The parieto-occipital sulcus was a reliable boundary between the cuneus and precuneus, with mean lengths of approximately 40 mm. The subparietal sulcus was described less frequently, highlighting a gap in the detailed morphometric literature.

Conclusion: Cadaveric evidence confirms both consistent and highly variable features of the medial cerebral sulci. The paucity of detailed morphometric descriptions for certain sulci, especially the subparietal, callosal, rostral and supra-rostral sulci, underscores the need for further targeted anatomical research.

Keywords: Clinical anatomy, Interhemispheric approach, Morphometry, Radiologic anatomy

INTRODUCTION

The medial surface of the human cerebral cortex contains consistently identifiable primary sulci that serve as stable landmark for cortical organisation and functional localisation [1,2]. The cingulate sulcus is a constant primary sulcus forming the superior boundary of the cingulate gyrus and is closely linked to cognitive, emotional, and motor integration [3,4]. Developmental studies demonstrate that the cingulate sulcus emerges early during cortical maturation, although its morphology shows marked interindividual, hemispheric, and gender-related variability [5,6].

In some individuals, a paracingulate sulcus is present dorsal and parallel to the cingulate sulcus, contributing to the structural subdivision of the medial frontal cortex [7,8]. Variations in the presence and extent of the paracingulate sulcus have been associated with differences In the cortical thickness, functional organisation, and hemispheric asymmetry [9,10]. Radiological and cadaveric studies further confirm gender-related and hemispheric differences in paracingulate sulcus morphology [11,12]. Posteriorly, the parieto-occipital sulcus forms a major fissural boundary separating the parietal and occipital lobes on the medial surface [13,14]. Although considered a reliable landmark, its length and configuration vary with age, population, and developmental factors, necessitating careful.

Interpretation in imaging and surgery [15,16]. Such differences extend beyond normal variation; recent studies indicate that reduced PCS length is associated with visual hallucinations in Parkinson's disease and altered cognition in schizophrenia [17,18].

The calcarine sulcus is one of the most constant sulci of the medial surface, dividing the occipital lobe into the cuneus and lingual gyrus and housing the primary visual cortex [19,20]. Morphometric MRI and cadaveric studies show that the calcarine sulcus exhibits relatively low interindividual variability and follows a predictable developmental timeline, supporting its reliability as a neuroanatomical landmark across the lifespan [21,22].

Cadaveric studies remain the gold standard for defining sulcal morphology; however, the literature is fragmented. Early anatomical reports were descriptive and based on small samples, whereas more recent neuroimaging studies often lack direct validation of dissection findings [23]. A systematic review of sulci and gyri morphology identified only a handful of cadaveric studies, most of which were methodologically limited and provided incomplete morphometric data. No comprehensive synthesis consolidates cadaveric evidence on the cingulate, paracingulate, rostral, callosal, parieto-occipital, and calcarine sulci. The absence of structured evidence mapping hinders the development of reliable anatomical reference standards.

The present scoping review charts cadaveric morphology and morphometry to specify which medial sulcal features are reliable or variable for surgical planning and MRI interpretation. Specifically, it will extract and synthesise quantitative and qualitative data, including sulcal length, depth, width, branching, laterality, and sex differences.

A consolidated understanding of sulcal variability has direct clinical significance. Sulci serve as fundamental surgical corridors and orientation markers in neurosurgery, and their anatomical variability influences both functional localisation and structural neuroimaging interpretation. By mapping the available cadaveric evidence, this review provides a foundational anatomical reference, informs the creation of more accurate brain atlases, and guides future clinical and neuroimaging research.

MATERIALS AND METHODS

The present scoping review was done between January, 2024 and June, 2025, and it was strictly adhered to the Joanna Briggs Institute (JBI) methodological framework for scoping reviews [24] and was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist [25]. The review protocol was registered on the Open Science Framework: https://osf.io/9c5av.

Inclusion and Exclusion criteria: The present study included original cadaveric anatomical studies that described the morphology and/or morphometry of the cingulate, paracingulate, calcarine, parieto-occipital, and subparietal sulci in the human brain. Both descriptive and quantitative studies were included in this review. The exclusion criteria were the studies including animal and foetal samples, and radiographic studies. This review focused on cadaveric studies to define the gold-standard morphology; radiologic correlates are summarised narratively in the Discussion to guide MRI interpretation. The studies considered eligible for inclusion in this scoping review were human cadaveric studies that evaluated adult cadaveric brain specimens. Radiological studies of paediatric and other clinical conditions, studies in other species, and articles without full text available were excluded from this scoping review.

Study Procedure

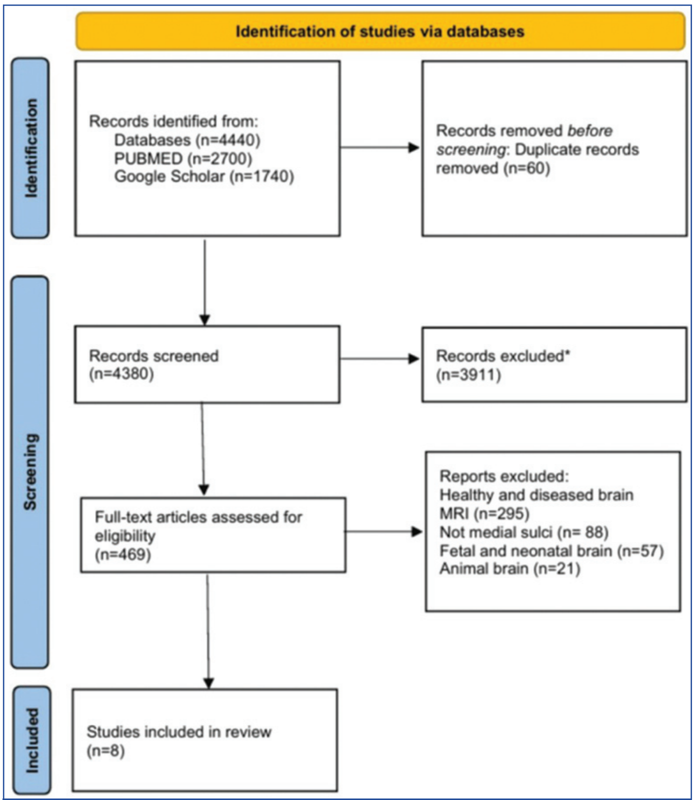
Information sources and search strategy: Databases: PubMed/MEDLINE, Embase, Scopus, and Google Scholar; full search strings, date ranges, and last search date are provided in the supplement; reference lists and forward citations were screened. The search strategy combined terms for each sulcus of interest with keywords related to cadaveric studies and neuroanatomy, for example, ("cingulate sulcus" OR "paracingulate sulcus" OR "calcarine sulcus" OR "parieto-occipital sulcus") AND ("cadaveric study" OR "gross anatomy" OR "dissection") AND ("morphometry" OR "morphological" OR "measurement" OR "depth" OR "length"). The reference lists of the included studies were screened to identify additional eligible publications.

Data charting process: Data extraction was performed independently by two reviewers using a standardised charting form. The extracted variables included author (s) and year of publication, country of study, sample size and number of hemispheres examined, population characteristics (age, sex, laterality if available), sulci examined, morphological classifications, morphometric measurements (length, branching patterns, distances to landmarks), notable anatomical variations, and key conclusions and clinical relevance.

Data Synthesis: The findings were synthesised descriptively and grouped by sulcus type. Morphometric results are summarised in tables with ranges, means, and standard deviations, where available. Morphological patterns were reported as frequencies and proportions. Owing to the descriptive nature of the data and variability in the measurement methods, no meta-analysis was performed.

RESULTS

A total of 4,440 records were retrieved, of which 60 duplicates were excluded. After title and abstract screening, 3,911 records were excluded from the study. Full-text review was performed for 469 articles, resulting in the exclusion of 461 papers for reasons including non-cadaveric methodology, paediatric or pathological specimens, non-medial sulci, and lack of full text. Ultimately, eight cadaveric studies met the inclusion criteria, collectively examining 422 hemispheres [12,15,26-31]. The study selection process is illustrated in [Table/Fig-1].



[Table/Fig-1]: Study selection process (PRISMA-ScR Checklist).
*Indicate how many records were excluded after title and abstract screening.

The included studies were conducted in diverse populations (European, Indian, Japanese). However, demographic information such as age and sex was incompletely reported, limiting subgroup analyses. The findings of included studies are presented in [Table/Fig-2] [12,15,26-31].

The cingulate sulcus is universally present and forms a dependable intraoperative landmark, whereas paracingulate variability mandates preoperative MRI correlation for medial frontal approaches to the brain. There is a lack of specific morphometric and morphological data from cadaveric studies reporting the average length of the cingulate sulcus in adult cadavers. Selahi O et al., stated that the PCS was present/prominent in approximately 25% of specimens, whereas the intralimbic sulcus was observed in approximately 15%. These dissection results align with the MRI findings that PCS prominence is a minority variant and support the observed sex differences (males showed more prominent PCS) [12]. Imada Y et al., (2021) performed detailed morphological observations and classified the medial frontal cortex (excluding the cingulate gyrus) into 2-4 gyri, with 56.6% of hemispheres showing 3 gyri [31]. These sulcal and gyral arrangements are considered reliable intraoperative landmarks for anterior interhemispheric approaches.

Calcarine Sulcus (CalS)

Mandal L et al., (2014) examined 106 cadaveric brain hemispheres and found bifurcation of the calcarine sulcus into two rami in 59.43% of specimens. Direct continuation to the lunate sulcus occurred in 31.13% of cases, with notable morphological variations, including "S" and "f" shaped terminations [26]. Thakuria NC et al., (2018) reported mean lengths of the anterior and posterior CalS segments as 23±0.4 mm and 35±0.3 mm,

Author and year	Country	Sample Size	Objective	Sulci examined	Morphological findings	Morphometric findings	Key Notes	Conclusion
Selahi O et al., 2022 [12]	Turkey	20 hemispheres, (149 Radiographic samples)	To identify and classify CS and PCS sulcal variations	CS and PCS	CS was present in all hemispheres. Out of 20 hemispheres, 2 had prominent, and 3 had an absence of PCS.	No cadaveric morphometric CS and PCS data were mentioned.	Useful in the interhemispheric approach for the Cingulate region.	There are 10% present and 15% absence of cadaveric PCS
Mandal L et al., 2014 [26]	India	106 hemispheres	To evaluate morphological variations of the occipital lobe sulci	CalS, POS (Lunate)	CalS - 40.56% had no rami at termination,55.66% divided once, 3.77 % divided twice, 57.69% crossed the occipital pole, 31.13% met Lunate sulcus.	Distance from splenium to termination of CalS 5.3±1.11 cm, Bifurcation of CalS to end of POS 3.42±0.73 cm.	High inter-individual and inter-hemispheric variability in occipital lobe sulcus.	Considerable morphological variability, branching, and hemispheric asymmetry in Cals and POS.
Nayak S et al., 2023 [27]	India	31 cadaveric (150 CT)	To locate the main sulci of the brain by using various anatomical landmarks.	CS, CalS, POS	No morphological data were mentioned for the sulcus.	Posterior part of the calcarine sulcus showed a significant difference (p-value=0.039) between right and left sides.	Supports safer neurosurgical planning despite sulcal asymmetry and variability.	There are significant hemispheric, gender and age-related variations present.
Gurer B et al., 2013 [15]	USA	56 hemispheres	To analyse the morphological patterns and variations of the subparietal and POS.	POS,Sub-parietal sulcus	POS was present in all hemispheres (100%) with straight patterns (30.4 %), T/Y shaped patterns (28.6%), and extended onto the lateral surface in 92.9%.	No morphometric values mentioned.	Both sulci show consistent presence but marked individual variability.	The knowledge of these variations is essential to improve safety and orientation during medial parietal neurosurgical approaches.
Malikovic A et al., 2012 [28]	Serbia	15 brains (10 male, 5 female) (30 hemispheres)	To define the variability of the occipital sulci including their presence, position, extent, intersections and length.	POS, CalS	POS Type-1 36.7% (straight course without ramification). Type-2 53.3% (Y-shaped form with two superolateral branches), type-3 10% (T-shaped form with horizontal superolateral branches) CalS type-1 63.3% (with a single apex), type-2 10% (with two apexes), type-3 (S-shaped), type-4 (in the form of horizontal sulcus).	Length was measured in the digitised images using ImageJ. POS 51.9±15.7 mm; CalS 104.6±29.7 mm, and the coefficient of variation is 30.3 and 28.4, respectively.	An Individual sulcal patterns anatomy must be considered to accurately localise visual areas and plan safer occipital neurosurgical procedures.	Human occipital sulci showed consistent presence with significant inter-individual and inter-hemispheric morphometric variability.
Thakuria NC et al., 2018 [29]	India	100 hemispheres	To study morphology of calcarine sulcus and compare the inter-individual and interhemispheric difference	CalS	CalS with ramification in both hemispheres (46%), with ramification in one hemisphere (18%), without ramification in both hemispheres (36%).	CalS length R 100.24 mm, L 103.12 mm.	Variation in calcarine sulcus length and posterior termination directly influences visual cortex involvement.	Significant interhemispheric variability in length and termination.
Flores LP., 2002 [30]	Brazil	26 hemispheres	To anatomically map the medial, lateral and deep structure of the occipital lobe	CalS, POS	CalS complete with side branches in 54% samples.	POS average length 32 mm.	The occipital lobe shows recurrent but variable sulcal patterns with measurable spatial consistency	These findings can be useful for the planning and performance of the interhemispheric approach
Imada Y et al., 2021 [31]	Japan	53 hemispheres	To clarify the anatomical relationship between the medial frontal cortex.	CS, PCS. Superior Rostral Sulcus (SRS), Inferior rostral sulcus (IRS), ventral MFC sulci	PCS present in 81%; PCS more frequent in left hemisphere; CS/PCS connected to SRS in 83%; sulcus ventral to IRS present in 34%.	No morphometric values provided.	Relevant for sulcal pattern classification of medial frontal cortex, helpful for contextual understanding of CS-PCS region.	The medial frontal cortex is a good landmark for intraoperative orientation in inter-hemispheric approach.

[Table/Fig-2]: Evidence of all eight studies on sulci presents on medial surface [12,15,26-31].
Cingulate Sulcus; Paracingulate Sulcus; Calcarine Sulcus; Parieto-occipital Sulcus

respectively, and morphometric differences between the right and left hemispheres were noted, but were statistically insignificant (n=100 hemispheres) [29]. Malikovic A et al., (2012) classified four morphological types: Type I (single apex), Type II (two apexes), Type III (S-shaped), and Type IV (horizontal) [28]. Approximately, 80% of the hemispheres demonstrated posterior bifurcation into upper and lower branches (n=30 hemispheres). In 13.3% of the cases, the posterior CalS was separated from the middle portion by a cuneolingual gyrus. These patterns are directly relevant to the localisation of the primary visual area (V1).

Parieto-Occipital Sulcus (POS)

The POS originated from the CalS and ran upwards and posteriorly towards the superomedial border. Nayak S et al.,

(2023) described the POS as originating from the CalS and extending toward the superomedial border in which the mean distance from CalS bifurcation to POS termination was 40 mm (n=31 hemispheres, 17 right and 14 left with unknown sex) [27]. [Table/Fig-3] [26-29] shows quantitative evidence of the length of sulci present in the medial cerebral cortex.

Malikovic A et al., (2012) identified three morphotypes: Type I (straight, unbranched), Type II (Y-shaped, more frequent in the left hemisphere), and Type III (T-shaped with horizontal superolateral branch, longest in right hemisphere). Across studies, the POS reliably demarcates the cuneus from the precuneus, serving as a robust anatomical landmark for visual cortical mapping. The POS consistently connects with the calcarine sulcus at a junction known as the cuneal point, serving as a reliable anatomical landmark for mapping the visual cortical areas. Although its length varies slightly between hemispheres, type 3 tends to be the longest, and type 1 is the shortest [28]. [Table/Fig-4] [12,15,26,27] provides a detailed summary of morphological evidence.

been observed in the neuroimaging literature and may influence approaches to the medial frontal lobe, where identification of a prominent paracingulate sulcus can alter surgical corridor [12].

Calcarine sulcus morphology exhibited less variation in the presence of the sulcus but notable variability in branching patterns and terminal morphology. Mandal L et al., (2014) documented bifurcation into two rami in over half of specimens and reported unusual terminations such as "S" and "f" shapes, which may pose challenges for the surgical localisation of the primary visual cortex [26]. The POS reliably demarcates the cuneus from the precuneus and anchors posterior interhemispheric navigation and provides intraoperative length expectations (40 mm) with noted morphotypes [28]. In contrast, the subparietal sulcus remains underdescribed in the cadaveric literature, despite its relevance to the posterior cingulate and retrosplenial cortex.

Radiological studies have also reported variability in paracingulate sulcus prevalence and morphology, often citing rates of 30-60%

Sulcus	Author	Year	Sample (Hemispheres)	Measurement methodology	Mean±SD	Coefficient Variance
Calcarine	Thakuria NC et al., [29]	2018	100	Length	Rt 100.24 mm, Lt 103.12 mm	NS
	Malikovic A et al., [28]	2012	30	Length	104.6±29.7 mm	28.4 %
POS	Nayak S et al., [27]	2023	53	Length	40±0.3 mm	NS
	Malikovic A et al., [28]	2012	30	Length	51.9±15.7 mm	30.3%
	Mandal L et al., [26]	2014	106	Length	34±0.7 mm	NS

[Table/Fig-3]: Morphometric evidence on sulci presents on medial surface. (NS: not specified) [26-29].

Sulcus	Authors	Year	Demography	Sample (Hemispheres)	Morphological findings	Variability
Cingulate	Selahi O et al., [12]	2022	Turkey	20	Present in all cases.	Associated with intralimbic sulcus (15%)
Paracingulate	Selahi O et al., [12]	2022	Turkey	20	Prominent (10%), Present (15%), Absent (75%)	Leftward asymmetry, more prominent in males.
Calcarine	Mandal Let al., [26]	2014	India	106	Bifurcation in (59.43 %), Continuation to lunate sulcus (31.13%)	"S" and "F" shaped terminations
Parieto- occipital	Nayak S et al., [27]	2023	India	31	Originates from Calcarine sulcus; distinct boundary between cuneus & precuneus	Morphology consistent
Subparietal	Gurer B et al., [15]	2013	USA	56	Consistent location relative to marginal ramus and POS	Lacks morphometric Details

[Table/Fig-4]: Morphological evidence of sulci present on the medial surface [12,15,26,27].

Subparietal, Callosal, and Rostral Sulci

The subparietal sulcus is consistently located relative to the marginal ramus of the cingulate sulcus and the POS [15], but no detailed morphometric data are available. The callosal and rostral sulci have rarely been described in cadaveric studies, and available reports have only provided qualitative anatomical descriptions without measurements. Overall, quantitative data on these sulci remain a major gap in the cadaveric neuroanatomical literature.

DISCUSSION

This scoping review provides a clinically oriented atlas of medial sulcal consistency and variability, specifying the implications for interhemispheric approaches and radiologic localisation. This synthesises cadaveric morphological and morphometric evidence for the medial cerebral sulci, specifically the cingulate, paracingulate, calcarine, parieto-occipital, rostral, and subparietal sulci, based on eight anatomical studies published between 1995 and 2024. By consolidating these findings, this review highlighted consistent sulcal patterns that serve as reliable intraoperative landmarks, as well as notable anatomical variations with potential surgical implications.

The cingulate sulcus emerged as a highly consistent structure present in all examined hemispheres across the included studies. In contrast, the paracingulate sulcus demonstrated substantial variability, with its absence in up to 75% of hemispheres, and a tendency for greater prominence on the left, particularly in males. This asymmetry has [1,3,6]. The present cadaveric synthesis showed a lower prevalence of prominent paracingulate sulci, which may reflect population-specific differences or methodological variations. Similarly, while imaging-based morphometry of the CalS often reports more symmetric lengths between the hemispheres, cadaveric evidence confirms small but measurable asymmetries [22]. In neurosurgery, the accurate identification of medial sulci is essential for safe entry into the interhemispheric fissures and deep cortical structures. The cingulate and paracingulate sulci guide access to the anterior cingulate gyrus and supplementary motor area, regions implicated in tumour resection and epilepsy surgery [31].

Variability in the presence of the paracingulate sulcus necessitates careful preoperative imaging correlation to avoid misinterpretation of cortical boundaries. The calcarine and parieto-occipital sulci are critical for preserving the visual pathway. Misidentification of CalS bifurcation or POS origin during posterior approaches could increase the risk of postoperative visual field deficits. Morphometric data from cadaveric studies provide intraoperative measurement benchmarks when sulci are obscured by pathology or distortion. The relative lack of quantitative data for the subparietal sulcus suggests an important avenue for future anatomical research. Given its proximity to the posterior cingulate cortex target in functional neurosurgery, detailed morphometric characterisation is warranted. The eight cadaveric studies showed major evidence gaps, with most providing only qualitative descriptions and very limited morphometric data for key medial sulci. Small, demographically inconsistent samples and variable measurement methods reduced comparability and prevented reliable assessment of population differences or hemispheric asymmetry. Several clinically important sulci, particularly the subparietal and callosal sulci, remained underexamined, and no study reported interobserver reliability. These gaps underscore the need for standardised, comprehensive cadaveric research to enhance the anatomical accuracy required for neurosurgical and radiological applications.

Limitation(s)

At the study level, the included cadaveric studies were limited by small sample sizes, heterogeneous demographic reporting, and variable preservation methods, which restrict generalisability and reproducibility of medial sulcal morphology and morphometry. At the outcome level, inconsistent sulcal definitions, non-standardised measurement techniques, and the frequent absence of quantitative depth and length data, particularly for the subparietal, callosal, and rostral sulci, which limited cross-study comparison and precluded synthesis of normative values. At the review level, this scoping review was constrained by reliance on descriptive evidence without meta-analytic methodology, potential publication bias, and limited radiologic and cadaveric correlation, underscoring the need for future standardised high-quality cadaveric studies with uniform morphometric protocols.

CONCLUSION(S)

The present scoping review demonstrates that while the cingulate and paracingulate sulci exhibit marked morphological variability, the calcarine and parieto-occipital sulci remain reliable landmarks for surgical and radiological orientation. Cadaveric evidence highlights consistent patterns essential for an interhemispheric approach but also reveals persistent gaps in morphometric data, particularly for the subparietal, callosal, and rostral sulci. These gaps limit accurate intraoperative navigation and underscore the need for standardised cadaveric measurements. Overall, the findings support the development of more refined anatomical reference standards and indicate priority areas for future neuroanatomical research. A clearer, more standardised cadaveric evidence base is essential to accurately define medial sulcal anatomy and to strengthen its role as a dependable guide for neurosurgical corridors and radiologic interpretation.

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