ORIGINAL COMMUNICATION

Anatomical Variations of the Insular Gyri: A Morphological Study and Proposal of Unified Classification

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The locations of gyral landmarks vary among individuals. This can be crucial during local landmark-based mapping of the human cortex, so the aim of the present study was to establish criteria for classifying the morphological variability of the human insula. The study was conducted on 50 isolated, randomly-selected adult cadaveric hemispheres, fixed in 10% formalin, and preserved in 70% ethanol (24 right and 26 left hemispheres). A thorough rating system, including bifid form (i.e., divided on top), branching or hypoplasia, was used to analyze the insular gyri. The number of all insular gyri ranged from four to six (mean = 5.16, SD = 0.65). Within the anterior lobule, the number of short gyri ranged from two to four (mean = 3.3, SD = 0.54). The middle short gyrus was the most variable. It was well-developed in 25 of the 50 cases (50%). Within the posterior lobule there were one or two long insular gyri (mean = 1.88, SD = 0.32). In 48 cases (96%), the anterior long gyrus was well-developed. A complete lack of the posterior long gyrus was noted in six of the 50 cases (12%). In conclusions, the accessory, the middle short, and the posterior long gyri of the insula were the most variable. The middle short gyrus was well-developed in only half of the cases. The number of insular gyri found in horizontal sections of the brain does not necessarily indicate their true number. Clin. Anat. 31:347–356, 2018. © 2018 Wiley Periodicals, Inc.

Key words: insula of Reil; insular cortex; insular gyri; insular sulci; pole of insula

INTRODUCTION

The insula, also known as the 'island of Sylvian fissure' (Meckel, 1817; cited in Swanson, 2015) or 'island of Reil' (Cruveilhier, 1836; cited in Swanson, 2015), is a deep cortical region surrounded by critical neural and vascular structures. It was first considered a cerebral lobe in 1975, when the 4th edition of the *Nomina Anatomica Paris* was published (Ribas, 2011; Stephani et al., 2011). From the embryological point

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of view, it overlies the area where the telencephalon and the diencephalon are fused together during development (Iani et al., 2013). Ultrastructurally, the insula is composed of the mesocortex, also referred to as the paralimbic cortex, and is thought to act as a relay between the limbic allocortex and the neocortex, the latter being phylogenetically younger and topographically more lateral than the former (Ribas, 2011; Wu and Lang, 2011; Iani et al., 2013).

The insula is morphologically divided by the central insular sulcus into anterior and posterior lobules, the former being larger than the latter (Türe et al., 1999; Guenot et al., 2004; Naidich et al., 2004; Stephani et al., 2011; Wu and Lang, 2011; Rosen et al., 2015). Both lobules comprise a variable number of cortical gyri. The anterior lobule typically displays anterior short (ASG), middle short (MSG), and posterior short (PSG) insular gyri, which are separated by the short insular sulcus and the precentral sulcus, respectively. An accessory gyrus (AG) and a transverse gyrus (TG) can also occur within the anterior insula (Türe et al., 1999; Naidich et al., 2004; Rosen et al., 2015). The posterior lobule contains the anterior (ALG) and posterior long (PLG) gyri, separated by the postcentral sulcus. The insula is separated from the adjacent regions of the cerebral hemisphere by three (Varnavas and Grand, 1999; Guenot et al., 2004; Mavridis et al., 2011) or four (Afif et al., 2009; Afif and Mertens, 2010) periinsular sulci.

Kang et al. (2004) reported that the 3D locations of gyral landmarks vary among individuals. Hence, an understanding of the gyral and sulcal organization of the insula in the human cortex could be important for both diagnostic neuroimaging and local landmark-based mapping of the area (Kang et al., 2004; Naidich et al., 2004; Afif et al., 2009; Rosen et al., 2015). However, there are no consistent data in the literature regarding the shape and number of the insular gyri and sulci. Therefore, the present study was conducted to provide a basis for a unified classification of variations in the gyrification of the insular cortex, based on simple visual criteria. It takes a novel approach in that data concerning the morphology of the insular cortex are supplemented by horizontal sections in cases where that morphology is atypical; this is particularly useful when the degree of development of the accessory and middle short gyri is assessed.

MATERIALS AND METHODS

The study was conducted on 50 isolated, randomly-selected adult cadaveric hemispheres (24 right and 26 left hemispheres), fixed in 10% formalin and preserved in 70% ethanol. The research project was approved by the local Bioethics Committee (protocol no. RNN/515/14/KB).

To expose the insula, the opercular parts of the frontal, parietal, and temporal lobes were removed. For comparison, horizontal incisions through each hemisphere were also made using a brain knife. The study used a simple visual classification of the insular gyri based on previous reports. Because there are no uniform criteria for assessing the morphology of the insular gyri, the nomenclature and classification applied by Türe et al. (1999) and Naidich et al. (2004) were used, modified according to observations from the present study (Table 1). In addition, the ratings criteria for gyral and sulcal conspicuity by Rosen et al. (2015) were taken into account. Using these sources, a thorough rating system was devised to categorize the insular gyri on the basis of their bifid form (i.e., divided on top) (Figs. 1 and 2), their branching (Figs. 1–3), or hypoplasia (Fig. 3).

TABLE 1. Nomenclature and Abbreviations Used in the Article and in Figure Descriptions

Abbreviation	Term, eventual synonym, and definition
AG	Accessory insular gyrus—when present, it branches from the first gyrus of the anterior lobule of the insula. It branches from the anterior surface of the anterior short gyrus more than one-third below its upper end.
TG	Transverse insular gyrus
ASG	Anterior short insular gyrus
MSG	Middle short insular gyrus
PSG	Posterior short insular gyrus (precentral insular gyrus—Afif et al., 2009; Afif and Mertens, 2010)
ALG	Anterior long insular gyrus (post-central insular gyrus—Afif et al., 2009; Afif and Mertens, 2010)
PLG	Posterior long insular gyrus (posterior insular gyrus—Afif et al., 2009; Afif and Mertens, 2010)
CS	Central insular sulcus—the borderline between the anterior and posterior lobule of the insula
SIS	Short insular sulcus (anterior insular sulcus—Afif et al., 2009; Afif and Mertens, 2010; Mavridis et al., 2011)
Pre-CS	Precentral insular sulcus—the sulcus located between the middle and posterior short insular gyri.
Post-CS	Postcentral insular sulcus—the sulcus located between the anterior and posterior long insular gyri.

Preliminary classification of the insular gyri was performed *in situ*. The lengths of the gyri and sulci were measured using a Digimatic digital caliper (Mitutoyo Company, Kawasaki-shi, Kanagawa, Japan). To verify the rating system, the specimens were photographed. The photographs were processed with MultiScanBase v.18.03 software (Computer Scanning System II, Warsaw, Poland) in order to recheck the measurements on each specimen. The length of each specific gyrus was measured from its top to its lowermost part. The length of the sulcus separating two adjacent gyri (the 'main' and 'secondary' gyri) was measured from the top of the main gyrus to the endpoint of the sulcus (Figs. 1 and 2).

A gyrus was classified as bifid at its upper end (Figs. 1 and 2) when the sulcus located between its split upper part extended up to 30% inferiorly along its length. It was classified as a 'branched gyrus' when the sulcus descended between 30 and 50% inferiorly (Figs. 1 and 2). It was classified as novel (separate)

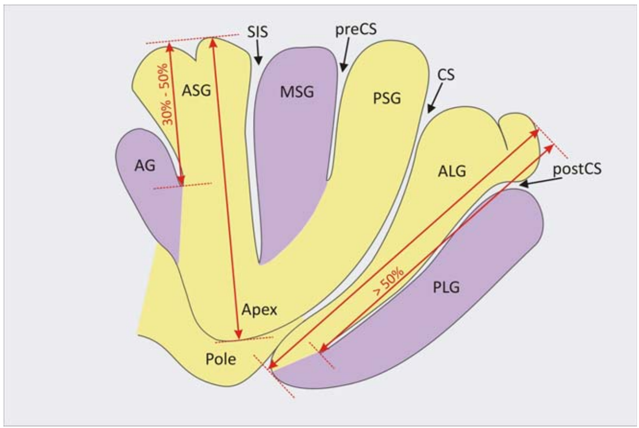

Fig. 1. Methods of classification of insular gyri. Examples of methods used to measure particular variables (i.e., the lengths of gyri and the lengths of the sulci separating adjacent gyri) are shown. A gyrus was classed as bifid at its upper end when the sulcus separating the split parts extended up to 30% inferiorly along its length (see ASG). When a sulcus extended between 30 and 50% inferiorly, it delineated a branched gyrus (see AG branching from ASG or MSG branching from PSG). A novel gyrus was delineated by a sulcus that extended >50% inferiorly (see PLG as a separate gyrus). SIS—short insular sulcus, preCS—precentral sulcus, CS—central insular sulcus, postCS—postcentral sulcus, AG—accessory gyrus, ASG—anterior short gyrus, MSG—middle short gyrus, PSG—posterior short gyrus, ALG—anterior long gyrus, PLG—posterior long gyrus, apex—apex of insula, pole—pole of insula. [Color figure can be viewed at wileyonlinelibrary.com]

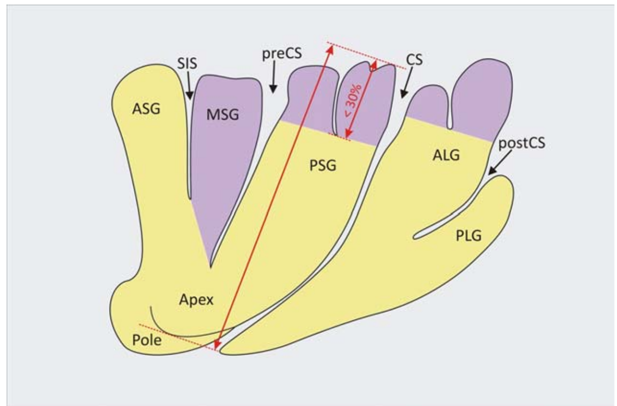

Fig. 2. Methods of classification of insular gyri. An example of a method used for measuring selected variables is shown. A gyrus was classed as bifid at its upper end when the sulcus separating the split parts extended up to 30% inferiorly along its length (see PSG and ALG). When a sulcus extended between 30 and 50% inferiorly, it delineated a branched gyrus (see MSG branching from ASG and PLG branching from ALG). SIS—short insular sulcus, preCS—precentral sulcus, CS—central insular sulcus, postCS—postcentral sulcus, AG—accessory gyrus, ASG—anterior short gyrus, MSG—middle short gyrus, PSG—posterior short gyrus, ALG—anterior long gyrus, PLG—posterior long gyrus, apex—apex of insula, pole—pole of insula. [Color figure can be viewed at wileyonlinelibrary.com]

when it was delineated by a sulcus that descended >50% inferiorly (Figs. 1–3).

Depending on the degree of formation, the gyri were classified as well-developed (reaching the convex surface of the insula), underdeveloped (depressed below the convex surface of the insula) or hypoplastic (vestigial, with surface level with the bases of the adjacent gyri) (Fig. 3). The degree of development of each individual gyrus was determined by analyzing the horizontal cross-sections. When an accessory gyrus (AG) was present, it formed the first gyrus of the anterior lobule and was included among the short insular gyri (Figs. 1 and 3). To distinguish between an AG and a bifid ASG, it was assumed that the AG branches from the anterior surface of the ASG more than one-third below its upper end (Figs. 1 and 3).

Like the gyri, the insular sulci were classified as well-developed, underdeveloped or absent, depending on the extent to which they separated the adjacent gyri. The term 'interrupted' was used when the course of the sulcus was interrupted by a part of the adjacent gyrus that projected to the opposite gyrus. The apex of the insula was defined as the most convex point in its direction, i.e., representing the summit of a pyramid formed by the insula. The classification of the apex was influenced by the combination of gyri involved in its formation. The term 'the pole of the insula', on the other hand, was used to refer to the area formed where the short gyrus bases connected, lying below, medially to or in most cases anteriorly to

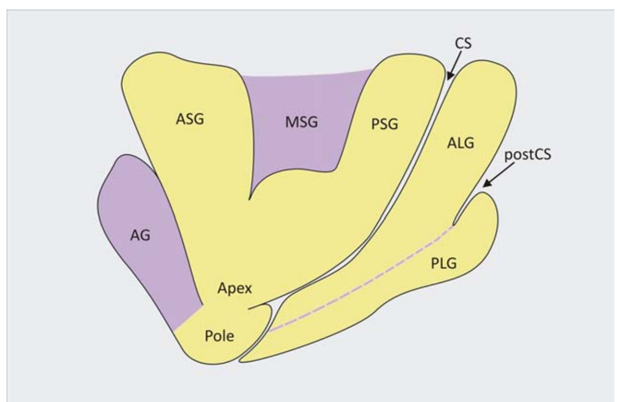

Fig. 3. Methods of classification of insular gyri based on the degree of their formation. The middle short gyrus (MSG) can be depressed below the convex surface of the insula or can be hypoplastic. The posterior long gyrus (PLG) is shown branching from the anterior long gyrus (ALG). CS—central insular sulcus, postCS—postcentral sulcus, AG—accessory gyrus, ASG—anterior short gyrus, PSG—posterior short gyrus, apex—apex of insula, pole—pole of insula. [Color figure can be viewed at wileyonlinelibrary.com]

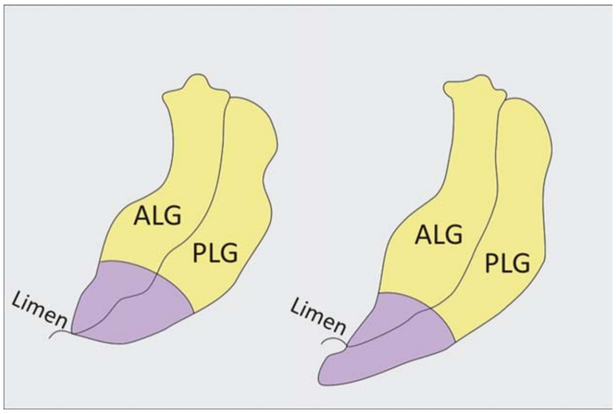

Fig. 4. Assessment criteria for anatomical variation of the pole of the posterior lobule. The pole of the posterior lobule forms the posterior wall of the limen of the insula. The anterior long gyrus (ALG) and the posterior long gyrus (PLG) can contribute equally to its formation (figure on the right, shaded area); alternatively, one of the long gyri can dominate in its formation (the example on the left shows domination of the posterior long gyrus in the formation of the pole of the posterior lobule). Limen—limen of the insula. [Color figure can be viewed at wileyonlinelibrary.com]

the apex. The limen of the insula was defined as the connection between the pole of the insula and the anterior perforated substance located medially. The pole of the posterior lobule forms the posterior wall of the limen of the insula. The extent to which the pole of the posterior lobule is formed by the ALG and PLG (Fig. 4) was assessed, and whether any of the long gyri dominate in its formation was considered (Fig. 4).

RESULTS

The central insular sulcus, the border between the anterior and posterior lobules, was well-developed (Fig. 5a) and extended from the limen along the entire length of the insula in 45 out of 50 cases (90%). In the remaining cases it did not extend for the entire length of the insula (2/50; 4%) or was interrupted by a streak of nervous tissue connecting the PSG to the ALG (3/50; 6%; Fig. 5b). The other sulci within the insula, namely the short insular, the precentral and the postcentral sulci, were well-developed in 47/50 (94%; Figs. 5a, 5b, and 6a), 44/50 (88%; Figs. 5a and 6a) and 22/50 (44%; Figs. 5b, 6a, 6c, and 6e) cases, respectively.

The mean number of all insular gyri in the specimens (excluding the transverse gyrus) was 5.16 (range 4–6, SD = 0.65). The mean number of short gyri found in the anterior lobule was 3.3 (range 2–4, SD = 0.54). All the specimens (100%) manifested well-developed ASG as well as PSG (Figs. 5–8). The MSG was more variable: it was well-developed in half of the cases (25/50, 50%) (Figs. 6a and 6b), depressed below the convex surface of the insula in 20/50 (40%) (Figs. 6c and 6d), and hypoplastic, that is, level with the bases of the adjacent gyri, in 5/50 (10%) (Figs. 6e and 6f). The short gyri were of similar width in 33/50 cases (66%), while the PSG was clearly wider in 17/50 (34%) (Fig. 5a).

Regarding the branching of the MSG from a specific adjacent gyrus, it most commonly originated from the PSG (24/50 cases; 48%: Figs. 5b and 7b). It branched from the ASG in 11/50 cases (22%: Fig. 7a), and from both from ASG and the PSG in 1/50 (2%: Fig. 7c). The MSG also formed a novel gyrus precisely between the ASG and PSG in 9/50 cases (18%: Fig. 7d). In 5/50 cases (10%) it was impossible to determine the origin

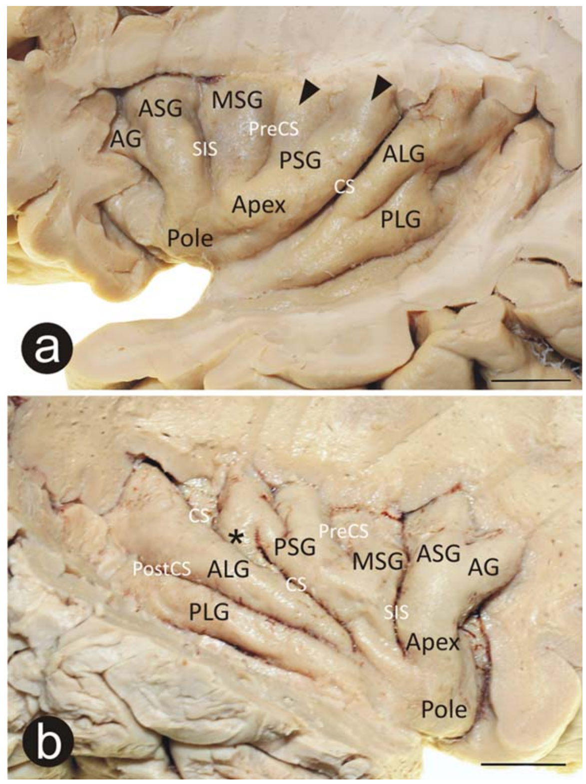

Fig. 5. Insular cortex of two different specimens exposed after removal of the overlying opercula. (**a**) Model example of arrangement of insular gyri and sulci. Left hemisphere, lateral view. A small accessory gyrus (AG) is visible. The posterior long gyrus (PLG) branching from the anterior long gyrus (ALG) has been visualized. In this specimen, the PSG was the widest of all the short insular gyri. Black arrowheads indicate bifurcation of the upper end of the posterior short gyrus (PSG). (**b**) Central sulcus (CS) interrupted by a streak of nervous tissue (marked by a black asterisk) connecting PSG and ALG. Right hemisphere, lateral view. Middle short gyrus (MSG) is depressed. PLG is distinctly separated from ALG and dominates at the pole of the posterior lobule. ASG—anterior short gyrus, pole—pole of the insula, PreCS—precentral sulcus, PostCS—postcentral sulcus, SIS—short insular sulcus, TG—transverse gyrus. Scale bars show 10 mm. [Color figure can be viewed at wileyonlinelibrary.com]

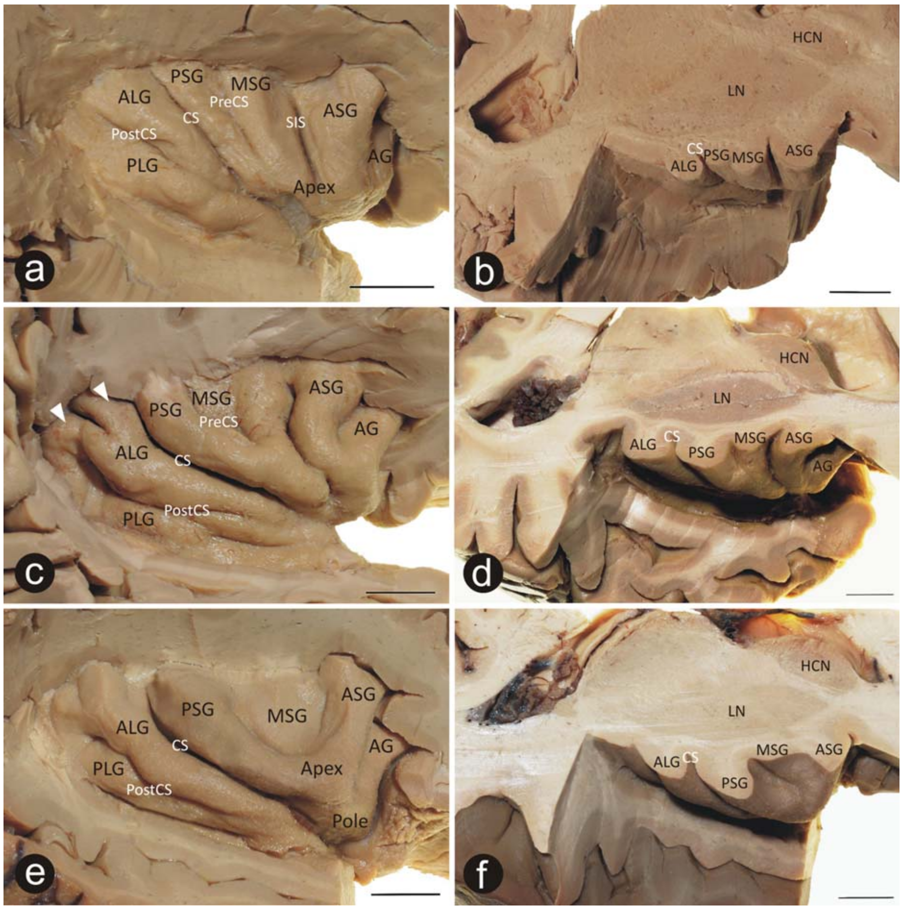

Fig. 6. Various types of formation of the middle short gyrus (MSG) shown from two different perspectives: lateral view and horizontal section. (**a**) Right hemisphere, lateral view on insular cortex. MSG is well-developed. Accessory gyrus (AG) is underdeveloped and remains confined to the anterior face of the insula.(**b**) Horizontal section of the specimen seen in figure 'a'. Accessory gyrus and posterior long gyrus (PLG) are not clearly revealed in this mode of visualization. (**c**) Right hemisphere, lateral view on insular cortex. MSG is depressed below the convex surface of the insula. (**d**) Horizontal section of the specimen seen in figure 'c'. An MSG depressed below the convex surface of the insula can clearly be distinguished. AG and PLG are not visualized in this section. (**e**) MSG is hypoplastic (in its place the pars opercularis of the inferior frontal gyrus and the inferior end of the precentral gyrus depressed). (f) Horizontal section of the specimen seen in figure 'e'. A fairly large gap between the anterior short gyrus (ASG) and posterior short gyrus (PSG) is visible. ALG—anterior long gyrus, HCN—head of caudate nucleus, LN—lentiform nucleus, TG—transverse gyrus. Scale bars show 10 mm. [Color figure can be viewed at wileyonlinelibrary.com]

of the ASG owing to its significant concavity or complete absence.

The accessory gyrus (AG) was often (18/50, 36%) small (Figs. 8c and 8d) or underdeveloped (Figs. 6a, 6b, and 7a), and remained confined to the anterior face of the insula. In 17 of the 50 cases (34%) it was well-developed and reached the convex surface of the insula, forming the first gyrus there (Figs. 8a and 8b). In 15/50 cases (30%) it was entirely absent (Figs. 7b and 8d). The transverse gyrus, in contrast, was observed in all specimens (100%); however, in 10/50 cases (20%) it was underdeveloped.

The apex of the insula was typically (16/50, 32%) found where the MSG and PSG merged (Fig. 5a), or else where the ASG and PSG merged (10/50, 20%) with no contribution from the MSG (Fig. 6e). A common variation was also formation of the apex by the ASG alone (9/50, 18%—Fig. 5b) or by the ASG and MSG (7/50, 14%—Fig. 7c). Quite often, the apex of the insula was grooved by an inferior extension of the precentral sulcus (24/50, 48%—Fig. 5a) or the short insular sulcus (22/50, 44%—Fig. 6a).

The mean number of long insular gyri forming the posterior lobule of the insula was 1.88 (range 1–2, SD = 0.32). In 48/50 cases (96%) the ALG was well-developed (Fig. 5a), and in 10 out of 35 cases (20%) it was distinctly wider and better developed than the PLG (Fig. 6c). The PLG was complete and distinctly separated from the ALG throughout its course in 27 of the 50 specimens examined (54%: Fig. 5b). On the

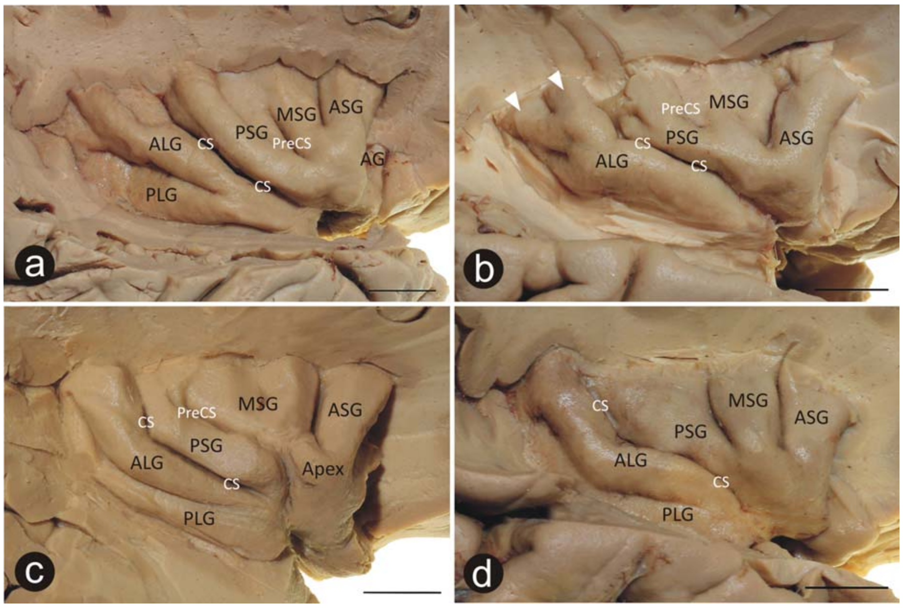

Fig. 7. Different types of branching of the middle short gyrus (MSG). MSG can branch from anterior short gyrus (ASG)—(**a**), posterior short gyrus (PSG)—(**b**), both ASG and PSG—(**c**) or be a separate structure—(**d**). AG—accessory gyrus, TG—transverse gyrus, ALG—anterior long gyrus, PLG—posterior long gyrus. Scale bars show 10 mm. [Color figure can be viewed at wileyonlinelibrary.com]

other hand, in 17 of the 50 cases (34%), it was merely a branch of the ALG, resembling a posteriorly directed 'outgrowth' from its back (Fig. 8c). The PLG was absent in six of the 50 cases (12%—Fig. 7b). There was also variability within the pole of the posterior lobule: the limen of the insula was most commonly formed there

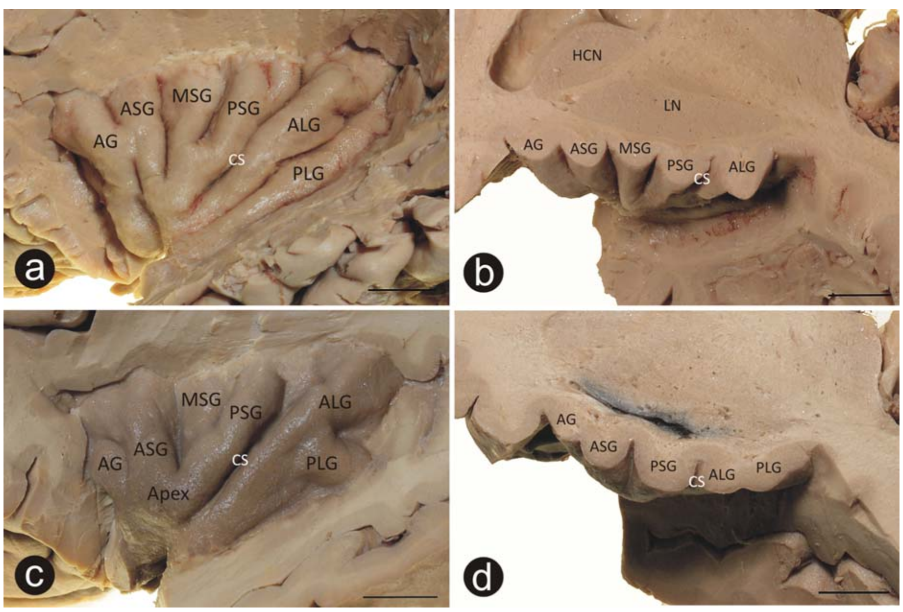

Fig. 8. Various degrees of development of the accessory gyrus shown from two different perspectives: lateral view and horizontal section. The accessory gyrus (AG) can be well-developed and form the first short gyrus of the convex surface of the insula (**a, b**) or can remain small and confined to the anterior face of the ASG (**c, d**). AG—accessory gyrus, TG—transverse gyrus, ASG—anterior short gyrus, MSG—middle short gyrus, PSG—posterior short gyrus, ALG—anterior long gyrus, PLG—posterior long gyrus. Scale bars show 10 mm. [Color figure can be viewed at wileyonlinelibrary.com]

jointly by the ALG and PLG (26/50, 52%) (Figs. 7a and 8a), while the ALG dominated in 20/50 cases (40%: Fig. 8c) and the PLG in 4/50 (8%: Figs. 5b and 6a).

Another type of morphological deviation was the gyrus splitting at the upper end, which was observed in 54% of cases (27/50) for ALG (Figs. 6c and 7b), 34% (17/50) for PSG (Fig. 5a), 22% (11/50) for ASG (Fig. 8c), 6% (3/50) for MSG, and 10% (550) for PLG. Our findings, together with those of previous studies, are presented in Tables (2–5).

DISCUSSION

Our findings regarding the overall number of insular gyri do not deviate significantly from those of previous reports (Table 2), but there are some discrepancies. In most studies, the minimum number of insular gyri was four (Varnavas and Grand, 1999; Naidich et al., 2004; Mavridis et al., 2011); however, Afif et al. (2009) and Afif and Mertens (2010) found five. Mavridis et al. (2011) reported a rare case where, contrasting with four right insular gyri, horizontal MRI revealed a single left insular gyrus in a patient with no insular pathology. However, any assessment of the number of gyri based on horizontal scans (or sections) should be viewed with caution, as it will not necessarily reflect the true number of insular gyri; this was noted by Mavridis et al. (2011) and in the present study. Typically, the maximal number of observed insular gyri is six (Naidich et al., 2004; Tanriover et al., 2004; Afif et al., 2009; Afif and Mertens, 2010); however, Varnavas and Grand (1999) and Mavridis et al. (2011), reported a maximum of seven.

Slight discrepancies among reports concerning the number of gyri in the anterior and posterior lobules of the insula are detailed in Table 2. Our findings indicate that the short gyri are more variable in number and morphology than the long gyri, as also observed in previous studies (Varnavas and Grand, 1999; Naidich et al., 2004; Afif et al., 2009; Mavridis et al., 2011; Rosen et al., 2015). The number of short gyri in the anterior lobule of the insula typically range from 2 to 4 (Naidich et al., 2004; Mavridis et al., 2011); however, Varnavas and Grand (1999) found five short gyri in one out of 53 hemispheres, and Tanriover et al. (2004), Afif et al. (2009), and Afif and Mertens (2010) reported the minimum number of gyri in the anterior lobule of the insula to be three.

Most studies have found the ASG to be the first well-developed gyrus on the convex surface of the insula. We found a well-developed AG to be the first insular gyrus in 34% of cases; similarly, Naidich et al. (2004) found this in 31.25%, while Türe et al. (1999) found it in 48% (Table 3). Tanriover et al. (2004) reported an AG in 60% of the hemispheres examined; however, they did not indicate how well this gyrus was developed. The results differ because the classification of the insular gyri is inconsistent. For example, a split at the upper end of the ASG (bifid ASG) could be interpreted as an AG being present; however, this mistake could be avoided by defining the AG as a gyrus that branches from the anterior surface of the

TABLE 2. Comparison of Total Numbers of Gyri and Numbers of the Short and Long Insular Gyri in Research by Different Authors

	Our study (50 hemispheres)	Naidich et al. (2004) (16 hemispheres in anatomical study)	Varnavas and Grand (1999) (53 hemispheres)	Tanriover et al. (2004) (43 hemispheres)	Afif and Mertens (2010) (20 hemispheres)	Afif et al. (2009) (75 hemispheres, MRI)	Mavridis et al. (2011) (28 hemispheres in anatomical study)
Full number of gyri	4: 14% (7/50) 5: 56% (28/50) 6: 30% (15/50)	4: 6.25% (1/16) 5: 62.5% (10/16) 6: 31.25% (5/16)	4: 3.8% (2/53) 5: 90.5% (48/53) 6: 3.8% (2/53) 7: 1.9% (1/53)	–	5: 90% (18/20) 6: 10% (2/20)	5: 96% (72/75) 6: 4% (3/75)	4: 32.14% (9/28) 5: 42.86% (12/28) 6: 17.86% (5/28) 7: 7.14% (2/28)
Number of short gyri	2: 4% (2/50) 3: 62% (31/50) 4: 34% (17/50)	2: 6.25% (1/16) 3: 62.5% (10/16) 4: 31.25% (5/16)	2: 1.89% (1/53) 3: 92.45% (49/53) 4: 3.8% (2/53) 5: 1.9% (1/53)	3: 95.3% (41/43) 4: 4.65% (2/43)	3: 90% (18/20) 4: 10% (2/20)	3: 96% (72/75) 4: 4% (3/75)	2: 32.14% (9/28) 3: 42.86% (12/28) 4: 25% (7/28)
Number of long gyri	1: 12% (6/50) 2: 88% (44/50)	2: 100% (16/16)	1 (ALG): 1.89% (1/53)	1: 7% (3/43) 2: 93% (40/43)	2: 100% (20/20)	2: 100% (75/75)	2: 92.86% (26/28) 3: 7.14% (2/28)

TABLE 3. Comparison of the Degree of Development of the Accessory Gyrus in Research by Different Authors

	Our study (50 hemispheres)	Naidich et al. (2004) (16 hemispheres in anatomic study)	Türe et al. (1999) (50 hemispheres)	Tanriover et al. (2004) (43 hemispheres)
Projects laterally and reaches the convex surface of the insula, forming the first gyrus of the convex surface	34% (17/50)	31.25% (5/16)	48%	'Present in 26 hemispheres (60%)'
Small and remained confined to the anterior face of the insula	36% (18/50)	62.5% (10/16) +1/16 prominent but still confined to the anterior surface of ASG	34%	
Absent	30% (15/50)	0% (0/16)	18%	40%

ASG more than one-third below its upper end. The same is true for the long gyri of the insula.

Three studies identified two gyri in 100% of specimens in the posterior lobule (Naidich et al., 2004; Afif et al., 2009; Afif and Mertens, 2010), while Mavridis et al. (2011) found three gyri in two cases out of 28 (7.14%). We found a PLG in 44 out of 50 (88%) specimens, while this PLG was complete and distinctly separated from the ALG throughout its course in 27 out of 50 (54%). Using a classification similar to ours, Rosen et al. (2015) found a PLG in 97 out of 113 hemispheres, 66% of them branching from the ALG. Therefore, to allow the variable insular morphology to be properly assessed, it is crucial to distinguish between the presence of a novel gyrus and a bifurcation at the upper end of a gyrus. As Naidich et al. (2004) reported, the ALG and PLG contributed equally to the formation of the pole of the posterior lobule in many cases.

As mentioned earlier, discrepancies among the results of previous studies could also be attributed to the use of different methods, such as MRI. Rosen et al. (2015) reported that ASG and PSG were easily identified on MRI, while AG and MSG were highly variable; AG, MSG, and PLG were the most anatomically variable and were either 'unclear' or 'unseen' in over 65% of insulae. Mavridis et al. (2011) reported that MRI was not as effective at distinguishing MSG as surgery ($P < 0.01$), so it could underestimate the true number of insular gyri. Following a three-dimensional in vivo anatomical visualization and characterization of insular gyri based on 3T MRI scans of healthy volunteers, Rosen et al. (2015) suggested that MSG are resolved more clearly in male subjects and in the left hemisphere. Our findings also indicate that the MSG was the most variable gyrus of the anterior lobule, and this is consistent with previous reports (Cunningham, 1891; Türe et al., 1999; Varnavas and Grand, 1999; Naidich et al., 2004) (Table 4). Varnavas and Grand (1999) and Naidich et al. (2004) suggested that excessive development of the frontoparietal operculum, which flanks the MSG, could explain the presence of depressed MSG types.

The insular cortex can be regarded as a map of all internal organs, its particular areas corresponding to particular organs (Craig, 2002, 2004). The combination

TABLE 4. Comparison of the Degree of Development of the Middle Short Gyrus in Research by Different Authors

	Our study (50 hemispheres)	Naidich et al. (2004) (16 hemispheres in anatomical study)	Türe et al. (1999) (50 hemispheres)	Varnavas and Grand (1999) (53 hemispheres)	Rosen et al. (2015)
MSG well developed	50% (25/50)	56.25% (9/16)	'Generally underdeveloped and only slightly convex'	'The least prominent'	Present in 81% of insulae; in 55% of the cases appeared less prominent relative to adjacent gyri
MSG depressed below the convex surface of the insula	40% (20/50)				
MSG hypoplastic	10% (5/50)	31.25% (5/16) In two other cases 'not identifiable' MRI: 33%			

TABLE 5. Comparison of the Morphology of the Upper Ends of Certain Gyri in Research by Different Authors

	Our study (50 hemispheres)	Naidich et al. (2004) (16 hemispheres in anatomic study + 300 in MRI)	Varnavas and Grand (1999) (53 hemispheres)
Bifurcation on the upper end of the gyrus	ASG: (11/50) MSG: (3/50) PSG: (17/50) ALG: (27/50) PLG: (5/50)	MRI: ASG: 10.33% (31/300) MSG: 0.6% (2/300) PSG: 5% (15/300) ALG: 15.67% (47/300) PLG: 0% (0/300)	ASG: 86.8% MSG: 21.6% PSG: 18.9% ALG: 54.7% PLG: 73.6%

of morphological knowledge with functional imaging could allow this map to be resolved in greater detail. Comparing the anatomical variability or stability of different structures to functions in this region provides illuminating insights. The highly-variable MSG is located in a region with some viscerosensory and gustatory sensory roles. These functions, viscerosensation and gustation, can vary among individuals, particularly when the more integrative functions of the insula, such as interoception (Critchley et al., 2004), affective pain dimensions (Ibañez et al., 2010), and pain processing (Afif et al., 2008) are considered. Conversely, the relatively anatomically stable ALG is located in a region associated with some somatosensory and thermosensory functions (Brooks et al., 2005). There are also suggestions that the morphology of the insula is altered in specific disorders. Jang et al. (2006) suggest that the insula can be structurally deformed in neurodevelopmental anomalies. The insular cortex can also be implicated in various neuropsychiatric diseases (Nagai et al., 2007). Assessing both the number and the morphology of the sulci and gyri of the insula can considerably enhance the safety of neurosurgical procedures performed on the lateral cerebral fossa (Kang et al., 2004; Tanriover et al., 2004; Wen et al., 2009; Rosen et al., 2015; Delion et al., 2016). Mavridis et al. (2011) indicated that an increased gyrus pattern (6–7 gyri) can result in a more complex insular anatomy, making a transsylvian approach more challenging. By analogy, a decreased gyral pattern (3–4 gyri) is associated with a less hidden cortex and simpler anatomy, which could make the surgical approach easier and safer. Moreover, Mavridis et al. (2011) suggested that the classic insular gyral pattern can be absent, probably as a normal anatomical variation.

Since the research was conducted on isolated cerebral hemispheres, the limitation of the present study is a lack of data on the age, sex and detailed medical history (including neurological and neuropsychiatric disorders) of the body donors. Nevertheless, we offer a concise proposal of an easily applicable unified classification of the insular gyri. Another limitation is the lack of clinical outcomes of the anatomical variations of the insular cortex presented here. In future, new quantitative morphometric studies will be necessary to investigate a possible correlation between these parameters.

CONCLUSIONS

The accessory, the middle short and the posterior long gyri of the insula were the most variable. The middle short gyrus was well-developed in only half of the cases. The most common morphological deviation of the gyri was the splitting of a given gyrus at the upper end. The number of insular gyri apparent in a horizontal section of the brain does not necessarily indicate their true number.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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