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ABSTRACT

SUMMARY: Craniopagus twins are a rare congenital malformation in which twins are conjoined at the head. Although there is high prenatal and postnatal mortality for craniopagus twins, successful separation has become more common due to advances in neuroimaging, neuroanesthesia, and neurosurgical techniques. Joined brain tissue, shared arteries and veins, and defects in the skull and dura make surgery technically challenging, and neuroimaging plays an important role in preoperative planning. Drawing on our experience from consultation for multiple successful separations of craniopagus twins, we discuss what radiologists need to know about the anatomy, classification, imaging techniques, and surgical management of craniopagus twins.

ABBREVIATIONS:

CPT = craniopagus twins; CVS = circumferential venous sinus; SDVS = shared dural venous sinuses; TA = total angular; TV = total vertical

Craniopagus twins (CPT) are a rare congenital malformation in which twins are conjoined at the head. It accounts for only 2%–6% of conjoined twins, with an incidence of approximately 1 in 2.5 million live births.\(^1\)\(^2\) The skulls are most often joined at homologous regions on each twin in both vertical and angular orientations, with the face and foramen magnum not primarily involved.\(^3\) CPT can manifest as total, the twins share dural venous sinuses (SDVS), and partial forms, with separate venous anatomy.\(^4\) Although there is high prenatal and postnatal mortality for CPT, successful separation has become more common due to advances in neuroimaging, neuroanesthesia, and neurosurgical techniques.\(^4\)\(^\text{–}^\text{20}\) Joined brain tissue, shared arteries and veins, and defects in the skull and dura make surgery technically challenging.\(^21\) Separation can take place in single or multistage procedures and has evolved as the understanding of the physiology, surgical techniques, and technology of CPT have improved.\(^16\)

Neuroimaging, including CT, MR imaging, and conventional angiography, plays an important role in mapping the shared arterial and venous structures, brain parenchyma, calvaria, and dura.\(^22\)\(^\text{–}^\text{24}\) Understanding the shared vascular anatomy is important for surgical planning because separating common vessels is associated with complications such as thrombosis, air embolism, infarction, and hemorrhage.\(^25\) Digital and physical 3D models generated from CT and MR imaging data are important tools for operative planning and as a guide in the operating room.\(^21\) We will review the preoperative radiologic evaluation of CPT, including the anatomy, classification systems, and surgical management, that is important for the radiologist to understand. We draw on our experience in consultation for multiple successful CPT separations with an experienced neurosurgical specialist in CPT.

Embryology

The monoamniotic, monochorionic type of monozygotic twinning has the greatest potential for leading to conjoined twins.\(^26\) The 2 main competing theories of how monoamniotic monozygotic twins conjoin are the “fission” and “fusion” theories.\(^27\) The fission theory suggests incomplete splitting or cleavage of the embryo at the primitive streak stage, leading to conjoined fetuses. This theory explains the apparent increase in the incidence of situs inversus and mirror imaging in conjoined twins, because a dividing cell or cell mass maintains mirror imaging.\(^26\) The fusion theory suggests that embryos reunite at vulnerable sites after initial complete
This theory accounts for the various angles at which conjoined twins can be fused, along either the dorsal-ventral axis or rostro-caudal axis. The extent to which the twins are conjoined and the time of fusion during development will determine how the anatomic structures will adapt.

**Classification Systems**

Multiple classification systems have been proposed for CPT (On-line Table). The first was developed by O’Connell, in which CPT were classified as partial or total; total CPT share an extensive surface area with widely connected cranial cavities, while in partial CPT, only a limited, superficial surface area is affected. He subdivided partial craniopagus twins on the basis of the degree of rotation of one head in relation to the other, with different deformities of the brain and abnormal circulation for each. Type I vertical CPT face the same direction, type II CPT face...
opposites sides, and type III twins have an intermediate angle of rotation.

On the basis of review of 64 cases, Stone and Goodrich defined partial CPT as lacking substantial shared dural venous sinuses, whereas total CPT share a large portion of their dural venous sinuses and present with pronounced brain compression, which leads to distortion within the cranium. They defined 2 main subtypes based on the long-axis angle between twins: angular and vertical (Fig 1). Vertical craniopagus calvaria is continuous and is further subdivided on the basis of intertwin axial rotation, similar to the O’Connell classification. Because the Stone and Goodrich classification is most commonly used, we will use it for discussion of CPT anatomy.

Anatomy
CPT are attached only at the calvaria, without involvement of the foramen magnum, skull base, vertebrae, or face. Other conjoined twinning variations involving the head include cephalopagus (involving the brain, face, thorax, and upper abdomen), parapagus diprosopus (2 faces on 1 head with 1 body), and rachipagus (joined dorsally along the vertebra and occasionally along the occiput). Conjunction is rarely symmetric and may involve any portion of the head, including underlying structures such as meninges, venous sinuses, or cortex. Configuration can vary on the basis of the attachment location and degree of rotation and angulation between the 2 twins, which will define the anatomy and difficulty of separation.

Partial CPT
Cranial unions in partial CPT are usually frontal and, less commonly, occipital or vertical biparietal. The junctional diameter is often smaller in the partial CPT than in other types of CPT, and an incomplete layer of bone may be present between the twins. In partial CPT, each child largely maintains independent calvarial convexities, except at the common area of skull junction. Cerebral deformities and compaction tend to be local and mild. The dura of each twin may be intact or deficient, and the cortical gyri may interdigitate. If the gyri do interdigitate, surgical separation is much more complex (Fig 2). Although the leptomeninges can sometimes be separable, when there is associated leptomeningeal vessel cross-over, the subsequent division will lead to some postoperative morbidity. Dural venous cross-circulation (SDVS) is absent or negligible. Children with partial CPT undergo successful separation at an earlier age than those with total CPT, and the separation more often results in survival of both children without severe disability.

Total Vertical CPT
The total vertical (TV) type of CPT consists of a longitudinal arrangement with the general appearance of 1 common continuous cranium housing 4 cerebral hemispheres. Minor longitudinal tilting, “stove-piping,” between the twins is common with a longitudinal intertwin axis or angle of 140°–180°. An incomplete or complete, single-layered transverse dural septum typically separates the cerebral hemispheres deep to the conjoined region (Fig 3). The falx cerebri is usually absent or anomalous. The major cerebral arterial supply is usually confined to each respective twin. On occasion, in addition to small interconnecting leptomeningeal vessels, conjoined brain tissue may contain a larger artery requiring division at surgery. There have been some reported cases of shared cerebral arterial supply, such as the shared middle cerebral artery circulation, which increases the complexity of a separation and may preclude safe separation.

There are a variety of cerebral venous abnormalities associated with total CPT. Because total CPT lack 2 complete dural envelopes, the peripheral dural shelf at the conjoined cerebral hemispheric zone encloses a circumferential venous sinus (CVS) (Fig 4). In TV CPT, the CVS generally traverses at least the hemicircumference of the conjoined region and replaces the absent superior sagittal sinus of both twins. The CVS assumes an increasingly oblique configuration with increasing interaxial rotation between the TV CPT, conforming to the lateral hemispheric cleavage plane. The CVS drains the homolateral superior cerebral hemispheres of each twin, empties into a common or asymmetrically shared posterior confluence of sinuses, and may connect the lateral sinus of one twin to the lateral sinus of the other. Other types of shared venous drainage include venous sinus “lakes,” a single shared superior sagittal sinus, or separate superior sagittal sinuses with variable interconnections between them.
system is an important prognostic indicator of successful separation because complications during separation can lead to substantial blood loss and a catastrophic result for 1 or both children. Both the CVS and SDVS are always present in TV forms of CPT, making successful surgical separation particularly hazardous.

The cerebral hemispheres in TV type I CPT demonstrate relatively symmetric superior biparietal or vertex compressive flattening. The anterior and middle fossae are spacious, while the posterior fossa tends to be small. Slight tilting or intertwin axial rotation leads to facial asymmetry. Later, positional plagiocephaly is common because intertwin orientation is fixed and individual twin movement is limited by the weight and positioning of the other twin. Progressive axial rotation between the twins during development in TV types II and III produces a progressively marked obliquity of the conjoined junction. This results in oblique cerebral hemispheric compression and craniofacial and middle and posterior fossa deformities. The marked bone, dural, and cerebral asymmetries in TV types II and III CPT compound the difficulties of surgical separation. In addition to compressed cerebral tissue in TV CPT (Fig 1C), a fused cerebral cortex and underlying white matter are also found.

**Total Angular CPT**

Total angular (TA) CPT have more acute intertwin longitudinal angulation and SDVS accompanied by complex, interconnecting venous channels (or CVS) and markedly distorted cerebral hemispheres. One twin’s brain can be inside the other twin’s calvaria, adding additional to the complexity of the surgical separation. Cerebral compaction, distortion, and displacement may result in skull base deformity. Most of the TA forms of CPT are joined asymmetrically with intertwin axial rotation, but some are roughly symmetric. TA CPT have shown greater extent of conjoined brain tissue, including the cerebellum, and cerebral arterial cross-filling than TV CPT (Fig 5 and On-line Fig 1). TA twins are, therefore, more challenging to separate.

**Anatomic Comorbidities.**

CPT often present with additional comorbidities, including cardiovascular, genitourinary, craniofacial, and neurologic abnormalities. Specific comorbidities include patent ductus arteriosus, aortic coarctation, hypertension, hyotension, genitourinary dysfunction and aplasia, hemiparesis, cleft lip and palate, anorectal agenesis, sirenomelia, and developmental delay. The presence of additional comorbidities increases the risk of surgery, and they are important considerations before operative management is decided. Imaging plays a key role in delineating all anatomic abnormalities present in each twin. TA CPT have a higher rate of comorbidities than TV twins, most notably genitourinary anomalies.

**Sedation Considerations**

CT and occasionally MR imaging can be performed in neonates with a mere “feed and wrap” approach without sedation. Older infants usually require general anesthesia for CT and MR imaging. Neuroanesthesia involvement is essential, using a dedicated team of anesthesiologists and equipment for each child, with closed-loop communication between teams to avoid confusion and drug errors and strict labeling of the twins to avoid confusion between them while dosing medications. Pharmacokinetics and pharmacodynamics in CPT are altered due to circulatory mixing, and medications administered to one twin may have unexpected effects on the other. Mask ventilation, access to airway, and intubation are also difficult due to the angle between the heads. During imaging, it is ideal to position the twins in the position planned for surgery. This helps the surgeons become oriented to the structures as they would appear on the table during surgery.

**Imaging Modalities**

**Prenatal Imaging.** Prenatal sonography (Fig 6A) and fetal MR imaging can be used to identify CPT in utero. The lack of
ionizing radiation in both modalities makes them ideal for prenatal imaging. Antenatal diagnosis of conjoined twins can be made with ultrasonography as early as 12 weeks’ gestation and is important for optimal obstetric management. Prenatal diagnosis may be suspected and confirmed if 2 fetuses cannot be visualized separately in a single gestational sac. A bifid appearance of the first trimester fetal pole, presence of >3 umbilical cord vessels, persistence of heads at the same level and body plane, and failure of the fetuses to change position relative to each other with time are other sonographic features that assist in making the diagnosis. 3D sonography may be more accurate than 2D sonography alone for defining the extent of the shared calvarial area and direction of the faces.

Fetal MR imaging allows superior assessment of intracranial structures, including the fetal brain, vasculature, and other soft-tissue structures, and is routinely used to evaluate CPT prenatally. Fast imaging techniques are used to image the rapidly moving fetal brain for structural detail, hemorrhage, and diffusion restriction, such as HASTE (Single-shot Fast Spin Echo), EPI, true fast imaging with steady-state precession, and DWI.

CT. High-resolution CT of the head with thin-section images using current pediatric, radiation dose-minimizing protocols is preferred. 3D reconstruction of the CT data is helpful to evaluate the extent of bone fusion (Fig 7A). These data can then be reconstructed into a 3D model, which can be used by the surgeon and radiologist in preoperative planning and intraoperative reference. CT angiography and venography provide adequate information related to vascularity in the conjoined area (Fig 7B–7C), with CT venography of paramount importance in presurgical planning before each stage of separation. Thin-section, axial raw data can be segmented for vein modeling (On-line Fig 2). The resolution of CT for the evaluation of vessels is superior to contrast-enhanced MR imaging. In most cases of CPT, after the initial presentation, CTA has excluded shared arterial vessels; stage 2 and later CT scans can be protocolled as CT venograms to follow venous redistribution and evaluate veins for separation.

MR Imaging. Brain MR imaging gives a detailed assessment of the brain anatomy and development, including the shared cortex,
venous sinuses, ventricular system, dural anatomic details, and other associated anomalies (Fig 8).\textsuperscript{8,42} MR angiography and venography can give detailed assessment of the vascular system, especially in shared areas. Time-resolved MRA (time-resolved imaging of contrast kinetics and time-resolved imaging with stochastic trajectories) helps to determine the extent of shared vasculature and the degree of vascular contribution by each twin. Just as CTA and CTV are superior for studying vessels, MR imaging is superior for studying the soft-tissue detail of the brain surface. Although the ultrafast sequences, such as single-shot T2-weighted images, have advantages in the constantly moving fetus, more conventional T1, T2, and T1-weighted images after IV gadolinium administration are used in the postnatal imaging.\textsuperscript{57} Volumetric imaging, such as T1-weighted MPRAGE and T2 sampling perfection with application-optimized contrasts by using different flip angle evolution (SPACE sequence; Siemens), provide high-resolution anatomic detail with isotropic voxels and can be used in surgical navigation or for modeling. In addition to a standard MR imaging acquisition, high-resolution, heavily T2-weighted volumetric sequences (eg, CISS, FIESTA, and so forth) of the brain surface interface, with a slightly smaller FOV, help evaluate the degree of brain fusion (On-line Fig 3). However, from our experience, even if MR imaging does not clearly show fusion of brain parenchyma, if there is no dural shelf present, fusion may still be present at surgery. In older children or adults, functional MR imaging can be used as a noninvasive way to define hemispheric language dominance and guide surgical planning. Steady-state fMRI could be used in younger children.

**Angiography**

DSA can help clarify the arterial and venous anatomy accurately preoperatively.\textsuperscript{8,20,67} Venography is performed by accessing the venous route of the child who has more fully formed sinuses. Balloon occlusion of the communication present between the venous sinuses can then show resulting hemodynamic changes that would result following surgical separation (Fig 9).\textsuperscript{20,67} Embolization of venous structures has also been described to promote the development of collaterals and facilitate an easier surgical venous

**FIG 7.** 3D surface rendering from CT (A) demonstrates suture patterns in the fused calvaria. A coronal contrast-enhanced CT venogram (B) demonstrates the orientation of the cerebral hemispheres and the presence of a dural septum (arrow). Maximum intensity projection of a CT venogram (C) demonstrates a shared superior sagittal sinus (arrow).

**FIG 8.** T2-weighted coronal image (A) is concerning for parenchymal bridging between the parietal lobes (arrow). Coronal postcontrast enhanced T1-weighted image (B) and dynamic MR angiography and venography (C–F) demonstrate a circumferential sinus communicating with both superior sagittal sinuses and dominant occipital sinuses without evidence of arterial anastomosis. Tractography (G) can demonstrate contiguity of white matter tracts in the cephalocaudal direction depicted in blue (arrow).
neurovascular models to better depict surgical anatomy (Online Fig 6) and transparent acrylic (Online Fig 4) to reconstruct cranial defects, and plan scalp tissue expander placement for adequate coverage.42,69

FIG 9. Multiple venous phase left ICA injections show how an occlusion balloon is used to define venous flow between twins (A and B). A coil (C) is then placed in a venous sinus to help promote venous collateral formation before surgery.

3D Models
Neuroradiologic imaging data have also produced life-sized, 3D, transparent acrylic (Online Fig 4A) and ceramic (Online Fig 5) models to better depict surgical anatomy (Online Fig 6) and holograms depicting the complex intracranial vascular anatomy in relation to the skull and brain.12,15,16,67–69 In the operating room, 3D models can be both physically printed for surgical reference or used in conjunction with intraoperative navigation technology.42,69 Additionally, 3D modeling can be used to plan the craniotomies, design split-thickness bone grafts (Online Fig 4B) to reconstruct cranial defects, and plan scalp tissue expander placement for adequate coverage.67,69

Operative Management
The goal of surgical separation of craniopagus twins involves separating shared structures, including cerebral vasculature and interdigitating brain, and reconstructing cranial structures for each twin. Single and multistage approaches have been used. In the single-stage procedure, the CVS is donated to one twin while reconstructing the sinus in the second twin. In the staged approach, one twin receives the CVS, while the other twin develops a deep venous drainage system during several months by serial ligation of draining veins (Online Figs 7 and 8). Multistage operations are often not required for partial CPT. Reconstruction includes adequate dural, cranial, and soft-tissue coverage. The dominant twin will have a thriving and more robust clinical pre-sence or used in conjunction with intraoperative navigation technology.42,69 Additionally, 3D modeling can be used to plan the craniotomies, design split-thickness bone grafts (Online Fig 4B) to reconstruct cranial defects, and plan scalp tissue expander placement for adequate coverage.67,69

CONCLUSIONS
Separation of CPT must be a well-orchestrated multidisciplinary effort. The care of these children is extremely resource-intensive, including critical care time, nursing, social support, travel, anesthesia, neurosurgery, diagnostic and interventional neuroradiology, administrative support, and the list continues. The neuroradiologist plays an important role in the care team of CPT, from initial evaluation through the operation and follow-up, using conventional imaging techniques (CT/MR imaging), angiography, and endovascular therapies and creating 3D models. Technologic advances that can greatly improve this field will include 3D virtual reality/augmented reality navigation to improve the knowledge of what lies behind a “wall” of fused brain in the operating theater, keeping loss of brain tissue to a minimum. The combination of high-resolution MR images and virtual reality 3D systems is already in use (12). Embolizing vessels will become even more precise as new endovascular devices and embolic materials become available, decreasing operative time needed for vascular ligation, providing a roadmap for surgeons when they divide veins (liquid embolic materials are clearly seen in superficial vessels with the naked eye), and further mitigating blood loss. With continued innovation, diagnostic and interventional neuroradiology plays an increasingly important role in the care of CPT.

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REFERENCES

1. Edmonds LD, Layde PM. Conjoined twins in the United States, 1970–1977. Teratology 1982;25:301–08 CrossRef Medline
2. Spitz L, Kiedy EM. Conjoined twins. JAMA 2003;289:1307–10 CrossRef Medline
3. Winston KR, Rockoff MA, Mullikeny JB, et al. Surgical division of craniopagi. Neurosurgery 1987;21:782–91 CrossRef Medline
4. Walker M, Browd SR. Craniopagus twins: embryology, classification, surgical anatomy, and separation. Childs Nerv Syst 2004;20:554–66 CrossRef Medline
5. Campbell S, Theile R, Stuart G, et al. Craniopagus: second Brisbane case: case report. J Neurosurg Pediatr 2017;20:307–13 CrossRef Medline
6. Yang Z, Xu G. Conjoined twins. Childs Nerv Syst 1997;13:780 Medline
7. Stone JL, Goodrich JT. The craniopagus malformation: classification and implications for surgical separation. Brain 2006;129(Pt 5):1084–95 CrossRef Medline
8. Nejat F, Habibi Z, Goudarzi M, et al. Emergency separation of craniopagus twins: case report. J Neurosurg Pediatr 2004;1:105–11 CrossRef Medline
9. Hoffman HJ. Craniopagus twins. Neurol Med Chir (Tokyo) 1997;37:780 Medline
10. Cywes S, Mill AJ, Rode H, et al. Conjoined twins: the Cape Town experience. Pediatr Surg Int 1997;12:234–48 CrossRef Medline
11. Campbell S. Separation of craniopagus twins: the Brisbane experience. Childs Nerv Syst 2004;20:601–96 CrossRef Medline
12. Goh KY. Separation surgery for total vertical craniopagus twins. Childs Nerv Syst 2004;20:567–75 CrossRef Medline
13. Frazee J, Fried I, Kawamoto H, et al. The separation of Guatemalan craniopagus twins. Childs Nerv Syst 2004;20:593–600 CrossRef Medline
14. Khan ZH, Hamidi S, Miri SM. Craniopagus, Laleh and Ladan twins, sagittal sinus. Turk Neurosurg 2007;17:27–32 Medline
15. Swift DM, Weprin B, Sklar F, et al. Total vertex craniopagus with combined venous drainage: case report of successful surgical separation. Childs Nerv Syst 2004;20:607–17 CrossRef Medline
16. Staffenberg DA, Goodrich JT. Separation of craniopagus twins with a staged approach. J Craniofac Surg 2012;23:2004–10 CrossRef Medline
17. Di Rocco C, Caldarelli M, Tamburrini G, et al. Craniopagus: the Thessaloniki–Rome experience. Childs Nerv Syst 2004;20:576–86 CrossRef Medline
18. Tanoury AC, Batatima JA, Velho MC, et al. Conjoined twins: twenty years’ experience at a reference center in Brazil. Clinics (Sao Paulo) 2013;68:371–77 CrossRef Medline
19. Ble RK, Seni K, Adjoussou S, et al. Craniopagus conjoined twins: difficulties of management in Africa. Gynecol Obstet Fertil 2008;36:56–59 Medline
20. Pai KM, Naidu RC, Raja A, et al. Surgical nuances in the separation of craniopagus twins: our experience and a follow-up of 15 years. Neurol India 2018;66:426–33 CrossRef Medline
21. Browd SR, Goodrich JT, Walker ML. Craniopagus twins. J Neurosurg Pediatr 2008;1:1–20 CrossRef Medline
22. Schindler E, Hajek P. Craniopagus twins: neuroradiological findings (CT, angiography, MRI). Neuroradiology 1988;30:11–16 CrossRef Medline
23. Sudha L, Dev B, Kamble R, et al. Role of biplane digital subtraction angiography, and 3D rotational angiography in craniopagus twins: a case report, detailed pictorial evaluation, and review of literature. J Pediatr Neurosci 2009;4:113–16 CrossRef Medline
24. Alokali RN, Ahmed ME, Al Feryan A, et al. Neurointerventional participation in craniopagus separation. Interv Neuroradiol 2015;21:552–57 CrossRef Medline
25. Bucholz RD, Yoon KW, Shively RE. Temporoparietal craniopagus: case report and review of the literature. J Neurosurg 1987;66:72–79 CrossRef Medline
26. Kaufman MH. The embryology of conjoined twins. Childs Nerv Syst 2004;20:508–25 CrossRef Medline
27. Spencer R. Theoretical and analytical embryology of conjoined twins, Part I: embryogenesis. Clin Anat 2000;13:36–53 CrossRef Medline
28. Gait G, Piazza G, Galassi E, et al. Craniopagus twins: an unsuccessful separation and a clinical review of the entity. Childs Nerv Syst 1987;3:327–33 CrossRef Medline
29. O’Connell JE. Craniopagus twins: surgical anatomy and embryology and their implications. J Neurol Neurosurg Psychiatry 1976;39:1–22 Medline
30. Spencer R. Conjoined Twins: Developmental Malformations and Clinical Implications. Johns Hopkins University Press; 2003
31. Baldwin M, Dekaban A. Cephalopagus twins seven years after separation: follow-up of a case. J Neurosurg 1965;23:199–203 CrossRef Medline
32. Wolfowitz J, Kerr EM, Levin SE, et al. Separation of craniopagus twins. S Afr Med J 1968;42:412–24 Medline
33. Lansdell H. Intelligence test scores from infancy to adulthood for a craniopagus twin pair neurosurgically separated at 4 months of age. Psychol Rep 1999;84:209–17 CrossRef Medline
34. Stathake MM, Venkannagari RR, Clauss RP. Scintigraphic evaluation of craniopagus twins. Br J Radiol 1998;71:1096–99 CrossRef Medline
35. Campbell S, Theile R, Stuart G, et al. Separation of craniopagus twins joined at the occiput: case report. J Neurosurg 2002;97:983–87 CrossRef Medline
36. Voris HC. Cranioplasty in a craniopagus twin. J Neurosurg 1963;20:145–47 CrossRef Medline
37. Voris HC, Slaughter WB, Christian JR, et al. Successful separation of craniopagus twins. J Neurosurg 1957;14:548–60 CrossRef Medline
38. Marcinski A, Lopatec HU, Wernemenski K, et al. Angiographic evaluation of conjoined twins. Pediatr Radiol 1978;6:230–32 CrossRef Medline
39. Konovalov AN, Valchis ChM. The successful separation of a craniopagus (in Russian). Zh Vopr Neirokhir Im N N Burdenko 1991;1:3–10 Medline
40. O’Connell JE. Surgical separation of two pairs of craniopagus twins. BMJ 1964;1:1333–36 Medline
41. Rutka JT, Souweidane M, ter Brugge K, et al. Separation of craniopagus twins in the era of modern neuroimaging, interventional neuroradiology, and frameless stereotaxy. Childs Nerv Syst 2004;20:587–92 CrossRef Medline
42. Sonnenburg WM. The blood vascular system in a parietal craniopagus. JAMA 1919;73:1345–48 CrossRef
43. Grossman HJ, Sugar O, Greeley PW, et al. Surgical separation in craniopagus. J Am Med Assoc 1953;153:201–07 CrossRef Medline
44. Winston KR. Craniopagia: anatomical characteristics and classification. Neurosurgery 1987;21:769–81 CrossRef Medline
45. Harvey DJ, Totonchi A, Gosain AK. Separation of craniopagus twins over the past 20 years: a systematic review of the variables that lead to successful separation. Plast Reconstr Surg 2016;138:190–200 CrossRef Medline
46. Staffenberg DA, Goodrich JT. Separation of craniopagus twins: an evolution in thought. Clin Plast Surg 2005;32:25–34, viii CrossRef Medline
47. Wilson H, Storer EH. Surgery in Siamese twins: a report of three sets of conjoined twins treated surgically. Ann Surg 1957;145:718–25 CrossRef Medline
48. Lenard HG, Schulte FJ. Polygraphic sleep study in craniopagus twins (where is the sleep transmitter)? J Neurol Neurosurg Psychiatry 1972;35:756–62 CrossRef Medline
49. Villarejo F, Soto M, Amaya C, et al. Total craniopagus twins. Childs Brain 1981;8:149–55 CrossRef Medline
van Ouwerkerk WJ, van den Berg R, Allison CE, et al. **Craniopagus: the Suriname-Amsterdam conjunction.** Childs Nerv Syst 2004;20:625–34 CrossRef Medline

Huang WQ, Fang JY, Xiao LC, et al. **Anesthetic management for separation of craniopagus twins.** Acta Anaesthesiol Scand 2004;48:919–21 CrossRef Medline

Cameron DE, Reitz BA, Carson BS, et al. **Separation of craniopagus Siamese twins using cardiopulmonary bypass and hypothermic circulatory arrest.** J Thorac Cardiovasc Surg 1989;98:961–67 CrossRef Medline

Drummond G, Scott P, Mackay D, et al. **Separation of the Baragwanath craniopagus twins.** Br J Plast Surg 1991;44:49–52 CrossRef Medline

Jansen O, Mehrabi VA, Sartor K. **Neuroradiological findings in adult cranially conjoined twins: case report.** J Neurosurg 1998;89:635–39 CrossRef Medline

O’Neill JA Jr, Holcomb GW 3rd, Schnaufer L, et al. **Surgical experience with thirteen conjoined twins.** Ann Surg 1988;208:299–312 Medline

O’Neill JA Jr, Holcomb GW 3rd, Schnaufer L, et al. **Surgical experience with thirteen conjoined twins.** Ann Surg 1988;208:299–312 Medline

McHugh K, Kiely EM, Spitz L. **Imaging of conjoined twins.** Pediatr Radiol 2006;36:899–910, quiz 1002–03 CrossRef Medline

Leelanukrom R, Somboonviboon W, Bunburaphong P, et al. **Anaesthetic experiences in three sets of conjoined twins in King Chulalongkorn Memorial Hospital.** Paediatr Anaesth 2004;14:176–83 CrossRef Medline

Vagyanavar R, Bhattacharyya A, Misra G, et al. **Craniopagus twins for magnetic resonance imaging.** Saudi J Anaesth 2017;11:509–10 CrossRef Medline

Thomas JM. **Anaesthesia for conjoined twins.** Childs Nerv Syst 2004;20:538–46 CrossRef Medline

Yadav M, Chilkala R, Kulkarni D, et al. **Anesthetic management of craniopagus conjoined twins in a remote location.** Saudi J Anaesth 2017;11:516–17 CrossRef Medline

Dasan TA, N G B, Anvekar SM. **A rare case of prenatally detected craniopagus twin.** J Clin Diagn Res 2015;9:TJ01–02 CrossRef Medline

Sharma UK, Dangol A, Chawla CD, et al. **Antenatal detection of conjoined twin.** J Nepal Med Assoc 2007;46:133–35 CrossRef Medline

Sanhal CY, Ozekinci M, Mendilcioglu I, et al. **Prenatal diagnosis of total type I vertical craniopagus with 3-dimensional sonography.** J Ultrasound Med 2014;33:179–81 CrossRef Medline

Rossi AC, Prefumo F. **Additional value of fetal magnetic resonance imaging in the prenatal diagnosis of central nervous system anomalies: a systematic review of the literature.** Ultrasound Obstet Gynecol 2014;44:388–93 CrossRef Medline

Saleem SN. **Fetal MRI: an approach to practice—a review.** J Adv Res 2014;5:507–23 CrossRef Medline

Harvey DJ, Vaca EE, Totonchi A, et al. **Eleven-year follow-up of craniopagus twins after unsuccessful attempt at separation: are they better off?** Cleft Palate Craniofac J 2019;56:817–22 CrossRef Medline

Goodrich JT, Staffenberg DA. **Craniopagus twins: clinical and surgical management.** Childs Nerv Syst 2004;20:618–24 CrossRef Medline

Heuer GG, Madsen PJ, Flanders TM, et al. **Separation of craniopagus twins by a multidisciplinary team.** N Engl J Med 2019;380:358–64 CrossRef Medline

Sugar O, Grossman H, Greely P, et al. **The Brodie craniopagus twins.** Trans Am Neurol Assoc 1953;3:198–99 Medline

Todorov AB, Cohen KL, Spiltoit V, et al. **Craniopagus twins.** J Neurol Neurosurg Psychiatry 1974;37:1291–98 CrossRef Medline

Piza-Katzer H. **Free allogeneic muscle transfer for cranial reconstruction.** Br J Plast Surg 2002;55:436–38 CrossRef Medline