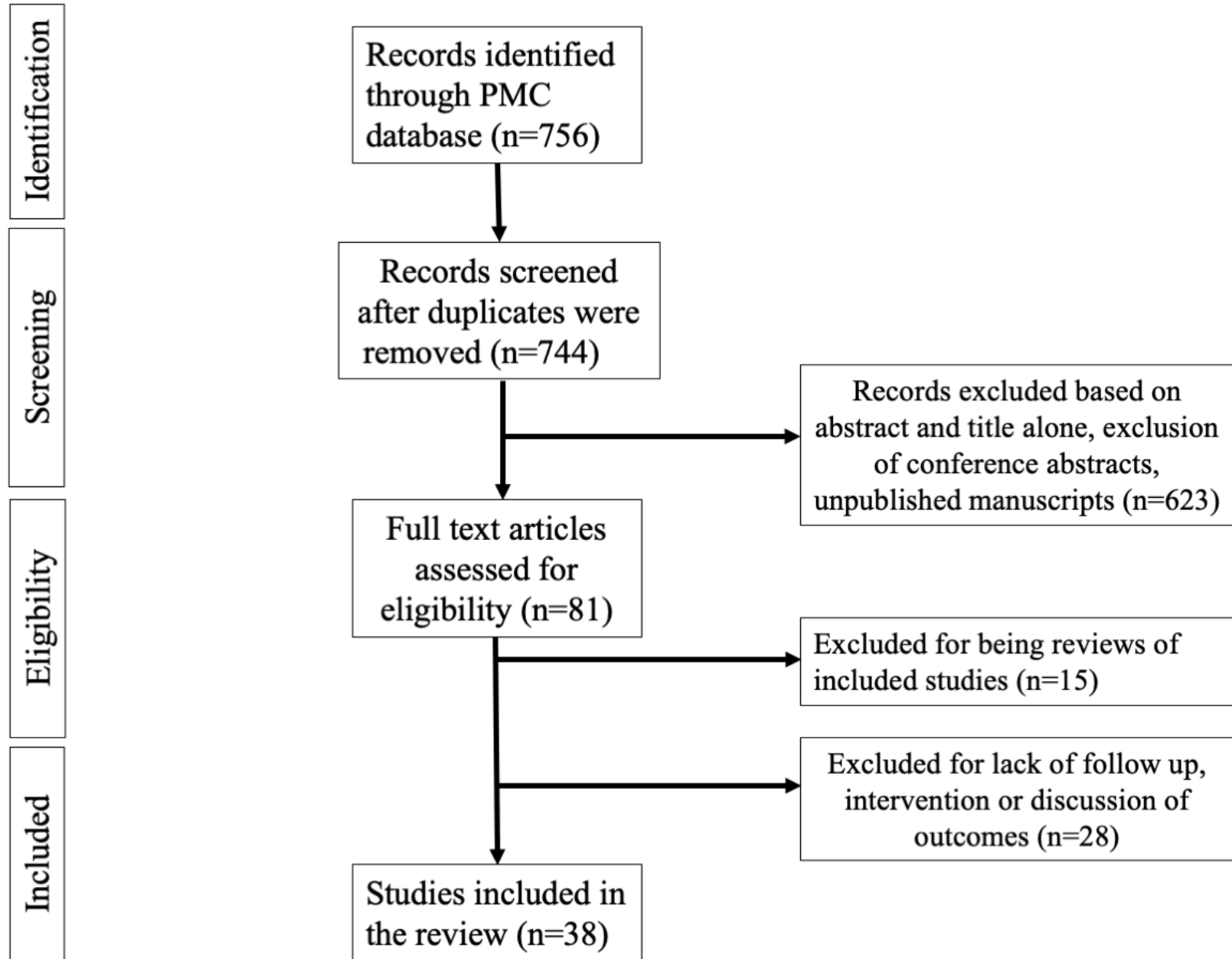


Supplemental Figure 1. PRISMA flow diagram of literature search.



Supplemental Table 1. Literature review of treatment of pulsatile tinnitus' causes. The myriad causes of pulsatile tinnitus have been treated by different modalities with varying levels of success and duration of follow-up. Prospective randomized trials are needed to better define appropriate treatment algorithms.

	Cause	Management	Intervention	Study Size (n =)	Study Design	Results Technical Success (%) Clinical Success (% follow up period) Complication rate (% major complication of death/stroke, follow up period)	Limitations	Reference
Vascular: Arterial	Atherosclerotic carotid artery disease	Surgery	Carotid endarterectomy	14	Case series	100% technical success 71% reported symptom relief at 6 week follow up 0% stroke/death rate	Retrospective study	Kirby-Bott and Gibbs 2004 [1]
	Atherosclerotic carotid artery disease	Endovascular Treatment	Carotid artery angioplasty and stenting	2	Case series	100% technical success 100% clinical success 0% complications	Stenotic lesions < 15 mm, small sample size	Inh et al 2013 [2]
	Atherosclerotic carotid artery disease	Endovascular treatment	Simultaneous extracranial endarterectomy and primary intrapetrous stenting	1	Case report	100% technical success 100% clinical success 0% complication rate	No follow up	Emery et al 1998 [3]
	Atherosclerotic carotid artery disease	Endovascular treatment	Simultaneous extracranial endarterectomy and primary intrapetrous stenting	1	Case report	100% technical success 100% clinical success, asymptomatic for 19 months 0% complication	Small sample size	Hartung et al 2004 [4]
	Intracranial arterial aneurysms	Endovascular Treatment	Coil embolization	1	Case report	100% technical success 100% clinical success for 4 years 0% complications	Sample size	Kim et al 2018 [5]

	Intracranial arterial aneurysm	Endovascular treatment	Coil embolization	1	Case report	100% technical success 100% clinical success up to 6 months 0% complication	Sample size	Kim et al 2012 [6]
	Intracranial arterial aneurysm	Endovascular treatment	Balloon embolization	1	Case report	100% technical success 100% clinical success for 6 months 0% serious complication, ear pain after treatment	Sample size	Willinsky et al 1987 [7]
	Arteriovenous malformations							
	Facial AVM	Endovascular Treatment	Coil embolization of superficial temporal artery	1	Case report	100% technical success 100% clinical success for 8 years 0% complication	Sample size	Chen et al 2018
	External ear AVM	Endovascular treatment	Preoperative embolization with surgical excision	1	Case report	100% technical success 100% clinical success 0% complication	Sample size Indirect symptom assessment at 2 year period	Woo et al 2008 [9]
	Parotid gland AVM	Surgery	Surgical ligation with partial resection of the left STA; parotidectomy	1	Case report	100% technical success 0% clinical success, persistent tinnitus after first surgery, then 100% clinical success with second 0% complication	Sample size, multiple surgeries	Selleck et al 2020 [10]
	Auricular AVM	Endovascular treatment + surgery	Pre-operative transarterial embolization with TFCA, glue and subsequent total mass excision	1	Case report	100% technical success 100% clinical success 100% complication – with ischemic skin necrosis	Sample size	Kim et al 2017 [11]
				1	Case report		Sample size	Aslan et al 2017

	External auditory canal/temporal bone AVM	Endovascular treatment + surgery	PVA embolization and subsequent surgical excision			<100% clinical success, with subsequent 100% technical success after surgery, 100% clinical success for up to 3 years, 0% complications		[12]
	Transverse sigmoid sinus dural AVM	Endovascular treatment	Coiling with dural venous occlusions	1	Case report	100% technical success 100% clinical success, 18 mo 0% complications	Sample size	de Paula Lucas et al 2010 [13]
	Marginal sinus fistulas	Endovascular treatment (88%), surgical (4%), combined (8%)	Transvenous (76%), transarterial (14%), combined (10%)	29	Case series	96% technical success 75% resolution of symptoms, 25% partial improvement in symptoms, 12% complications	Various treatment modalities	Caton et al 2021 [14]
	Condylar vein fistulas (anterior + posterior)	Endovascular treatment	Transvenous embolization	6	Case series	100% technical success 100% clinical success, 2 y 0% complications, 2 y	Sample size	Hellstern et al 2019 [15]
	Posterior condylar canal fistula	Endovascular treatment	Transvenous embolization	1	Case report	100% technical success 100% clinical success 0% complications	Sample size	Brinjikji et al 2020 [16]
	Traumatic CCF	Endovascular treatment	Transvenous and transarterial coil embolization	1	Case report	100% technical success 100% clinical success, 7 weeks 0% complications	Sample size Short follow up	Lerut et al 2007 [17]
	Persistent primitive trigeminal artery aneurysm/CCF	Endovascular treatment	Coil and onyx embolization	1	Case report	100% technical success 100% clinical success, 3 mo 0% complications, 3 mo	Sample size Short follow up	Fan et al 2019 [18]
	CCF/Internal Carotid Artery Aneurysm	Surgery + Endovascular treatment	Embolization of cavernous sinus and fistula with superficial temporal artery + MCA anastomosis with ICA occlusion	1	Case report	100% technical success 100% clinical success, 2 months 0% complication	Sample size	Nakahara et al 2019[19]

	Rete mirabile	Conservative management	Conservative management	1	Case report	N/A technical success 0% clinical success, 6 mo 0% complications	Lack of clinical success	Mondel et al 2017[20]
	Aberrant internal carotid artery	Surgery	Endoaural approach surgical myringoplasty	1	Case report	100% technical success 100% clinical success, 1 y follow up 0% complications, 1 y	Sample size	Honkura et al 2014 [21]
	Aberrant internal carotid artery	Surgery	Separation of aberrant ICA from promontorium tympani and coagulation	1	Case report	100% technical success 100% clinical success, 7 mo 0% complications, 7 mo	Sample size	Song et al 2012 [22]
	Duplicated, aberrant internal carotid artery	Conservative management	Conservative management with regular follow up	1	Case report	N/A technical success 0% clinical success at 1 year N/A complications	Sample size	Anagiotos et al 2019 [23]
	Aberrant internal carotid artery	Surgery	Placement of tragal cartilage over carotid canal	1	Case report	100% technical success 100% clinical success, 3 mo 0% complications, 3 mo	Sample size, no long-term follow up	Hashim et al 2021[24]
	Aneurysm of an aberrant ICA	Endovascular treatment + Surgery	Endovascular internal trapping and common carotid artery to MCA bypass	1	Case report	100% technical success 100% clinical success, 6 months 0% complications	Sample size	Kawamura et al 2017[25]
	Persistent stapedia artery	Surgery	Resection of PSA	1	Case report	100% technical success 100% clinical success, immediate 0% complications, immediate	Lack of long term follow up	Murphy et al 1995 [26]
		Surgery	Stapedotomy	1	Case report	100% technical success 100% clinical success, immediate 0% complications, immediate	Lack of long term follow up	Pirodda et al 1994[27]
Vascular: Venous	Idiopathic intracranial hypertension	Lifestyle modifications Medications	Weight reduction and acetazolamide	165	Multicenter double blind, randomized	N/A technical success Decreased papilledema in acetazolamide + weight reduction group, 6 mo	Resolution of pulsatile tinnitus was	NORDIC Trial 2014 [28]

			versus weight reduction only			0% complications, 6 mo	not a primary outcome	
		Endovascular Treatment	Stenting	154	Systematic review	100% technical success 90% clinical success, variable follow up	Variable follow up; discussion of complications limited	Nicholson et al 2019 [29]
		Surgery	Bariatric surgery	22	Single center retrospective study	100% technical success 95% clinical success, 1 year 0% major complications, 1 years	4 patients lost to follow up, lack of control group	Sugerman et al 1999 [30]
		Endovascular treatment	Venous stenting	15	Single center retrospective analysis	100% technical success 79% clinical success, 14 mo 0% complication	Lack of control group	Fields et al 2013 [31]
		Endovascular treatment	Venous stenting	29	Single center prospective analysis	100% technical success 90% clinical success, 12 mo 0% complications, 12 mo	Lack of control group	Boddu et al 2016 [32]
		Endovascular treatment	Venous stenting	79	Single center retrospective analysis	100% technical success 86% clinical success, 18 mo 0% complications	Pulsatile tinnitus not a primary outcome, primary outcome was elevated opening pressure	Kahan et al 2021 [33]
		Endovascular treatment	Venous stenting	81	Single center prospective analysis	100% technical success 46% clinical success, 10 mo 0% complications, 10 mo	Pre-intervention pulsatile tinnitus scoring was not performed	Garner et al 2021 [34]
		Surgery versus weight management program	Bariatric Surgery (Roux-en-Y gastric bypass),	66	Multicenter Randomized control trial	100% technical success Significant decrease in ICP in bariatric surgery group, 12 mo 0% complications, 12 mo	Pulsatile tinnitus was	Mollan et al 2021 [35]

			weight management					
		Various	Optic nerve sheath fenestration	712	Systematic review/metanalysis	100% technical success 80% clinical success (papilledema), 21 mo 1.5% complications, 21 mo	not a primary outcome; three different types of bariatric surgery were offered to patients; predominantly female study population	Satti et al 2015 [36]
			CSF diversion	435		100% technical success 97% clinical success, 23 mo 2.9% complications, 23 mo		
			Venous stenting	136		100% technical success 64% clinical success (visual acuity), 42 mo 0% complications, 42 mo		
		Various	Optic nerve sheath fenestration	341	Systemic review/meta-analysis	100% technical success 67% clinical success, 44 mo 0% complications, 44 mo	Pulsatile tinnitus was not a primary outcome	Kalyvas et al 2017 [37]
			CSF Diversion/Lumboperitoneal shunting	128		100% technical success 69% clinical success, 40 mo 0% complications, 40 mo		
			Ventriculoperitoneal shunting	26		100% technical success 65% clinical success, 22 mo 4% complications, 22 mo		
			Venous sinus stenting	136				

	Abnormalities of the jugular bulb							
	Jugular bulb diverticulum	Endovascular treatment	Coil embolization	1	Case report	00% technical success 100% clinical success, 10 mo 0% complications, 10 months	Follow up, sample size	Mortimer et al 2015 [38]
	Jugular bulb diverticulum	Endovascular treatment	WEB	1	Case report	100% technical success, 100% clinical success, 2 mo 0% complication	Sample size	Drescher et al 2020 [39]
	High riding jugular bulb with associated sigmoid sinus stenosis and diverticulum	Endovascular treatment	Stent placement across sigmoid sinus with coil embolization of the diverticulum	1	Case report	100% technical success, 100% clinical success, 16 mo 0% complications, 16 mo	Sample size	Trivelato et al 2015 [40]
	Dehiscent high jugular bulb	Surgical	Surgical reconstruction of the middle ear floor	7	Retrospective case series	100% technical success 57% clinical success, 28 mo 0% major complications, 28 mo 14% with increased ICP	Variability in technique in reconstruction of the floor Sample size	El-Begermy et al 2010 [41]
	Dehiscent high jugular bulb	Surgical	Separate the tympanic membrane from the jugular bulb using packed Gelfoam	1	Case report	100% technical success 100% clinical success, 3 y 0% complications, 3 y	Sample size	Shaikh et al 2013 [42]
	Abnormalities of the transverse/sigmoid sinus							
	Dominant sigmoid sinus with focal dehiscence	Surgery	Transmastoid reconstruction of the sigmoid sinus	8	Retrospective analysis	100% technical success 87% clinical success, 9.5 mo 0% complications, increased ICP in 13%	Majority of study participants are female	Kim et al 2016 [43]
	Sigmoid sinus diverticulum	Endovascular treatment	Coil embolization	1	Case Report	100% technical success 100% clinical success, 6 mo 0% complications, 6 mo	Sample size	Zenteno et al 2004 [44]

	Transverse sigmoid sinus diverticulum	Endovascular Treatment	Coil embolization	1	Case Report	100% technical success 100% clinical success, 1 y 0% complication, 1y	Sample size	Gard et al 2009 [45]
	Sigmoid sinus diverticulum		Coil embolization	1	Case Report	100% technical success 100% clinical success, 8 mo 0% complication, 8 mo	Sample size	Houdart et al 2000 [46]
	Sigmoid sinus diverticulum	Endovascular Treatment	Coil embolization	1	Case Report	100% technical success 100% clinical success, 12 mo 100% complication – cerebellar ischemic stroke, 2 mo	Sample size	Sanchez et al 2002 [47]
	Sigmoid sinus diverticulum	Endovascular treatment	Balloon assisted embolization	1	Case Report	100% technical success 90% clinical success, 12 mo 0% complications, 12 mo	Sample size	Mehanna et al 2010 [48]
	Sigmoid sinus diverticulum	Endovascular treatment	Coil embolization	1	Case Report	100% technical success 100% clinical success, 6 mo 0% complications, 6 mo	Sample size, follow up interval	Amans et al 2014 [49]
	Sigmoid sinus diverticulum with sigmoid sinus wall dehiscence	Surgery, conservative management	Sigmoid sinus wall reconstruction or conservative management	28	Retrospective Case Control	100% technical success 68% clinical success in surgery versus 0% clinical success for those with conservative management, 16 mo 0% complications, 16 mo	Variability in surgical techniques used, majority of participants are female	Wang et al 2015 [50]
	Sigmoid sinus wall abnormalities with diverticulum	Surgery	Transtemporal sinus wall reconstruction	40	Single center Retrospective	90% technical success 90% clinical success, 1mo 0% complications, 1 mo	Short interval follow up	Eisenman et al 2018 [51]
	Sigmoid sinus wall anomaly	Surgery	Transmastoid sigmoid sinus	40		100% technical success		Raghavan et al 2016 [52]

	Venous sinus diverticulum at the junction of the transverse and sigmoid sinuses	Endovascular treatment	wall reconstruction	2	Single center retrospective	100% clinical success, 12 mo 0% complications, 12 mo	Follow up period was variable/not discussed for every patient	Shastri et al 2017 [53]
	Lateral sinus stenosis	Endovascular treatment	Coil embolization	14	Case series	100% technical success 93% clinical success, 12 mo 0% complications	Sample size	Lenck et al 2017 [54]
			Venous stenting		Case series		Unblinded assessment, 2 patients had IHH	
	Dilated mastoid emissary vein	Endovascular treatment	Embolization	6	Case series	100% technical success 33% clinical success, 6 mo 0% complications, 6 mo	Sample size, clinically successful only in patients with venous PT (versus neutral PT where pre-operative vascular compression did not change symptoms)	Eliezer et al 2020 [55]
	Dilated mastoid emissary vein	Endovascular treatment	Transvenous embolization of large dilated mastoid emissary vein	1	Case report	100% technical success 100% clinical success, 6 mo 0% complications, 6 mo	Sample size	Abdalkader et al 2021 [56]
	Dilated mastoid emissary vein	Surgery	Surgical clipping of mastoid emissary vein	1	Case report	100% technical success 100% clinical success, 3 y 0% complications, 3 y	Sample size	Kim et al 2021 [57]
Non-vascular - Structural	Glomus tumor	Radiation	Gamma knife	53	Multicenter-retrospective	100% technical success 49% clinical success, 50.5 mo 0% complications, 50.5	Variability in follow up (5-220 mo)	Sheehan et al 2012 [58]
	Glomus tumor	Radiation	Gamma knife	10		100% technical success		

	Glomus tumor	Surgery and endovascular treatment	Surgery with preoperative embolization using ethanol	6	Single institution retrospective case series Case series	40% clinical success, 27.6 mo 0% complications, 27.6 mo 100% technical success 100% clinical success, 21.3 0% complications, 21. 3 mo	Sample size, variable decreases in tumor size, variable follow up (mean reported) Sample size	Dobberpuhl et al 2016 [59] Devuyt et al 2016 [60]
	Superior semicircular canal dehiscence	Surgery	Plugging + resurfacing via the middle fossa	12	Case series	100% technical success 83% clinical success, 5 mo 0% complications, 0 mo	Short follow up interval	Chung et al 2016 [61]
12				Case series	100% technical success 100% clinical success, 31.1 mo 0% complications, 31.1 m	Thomeer et al 2016 [62]		
3			Case series	100% technical success 66% resolution of tinnitus, 4 mo 0% complications, 4 mo	Sample size Limited follow up	Hillman et al 2006 [63]		
			Transmastoid plugging	13	Retrospective case series	100% technical success 84% clinical success (1 mo-2 y) 0% complication	Sample size Variable follow up	Haesendock et al 2016[64]
	Anemia	Medical treatment	Supplementation with Vitamin B12	1	Case report	N/a technical success 100% clinical success, 3 w 0% complications, 3 w	Sample size Short term follow up	Cochran and Kosmicki 1987 [65]
		Medical treatment	Supplementation with iron and or blood transfusions if patients had IDA	13	Single institution cross sectional study	100% technical success 75% clinical success, 1 mo 0% complications, 1 mo	Sample size Short term follow-up Female predominant population Not controlled by co-morbidities	Sunwoo et al 2018[66]

Non-vascular – Systemic	Subjective tinnitus	Cognitive behavioral therapy	Tinnitus retraining counselling + audiological rehabilitation versus usual care	492	Double blind randomized control trial	N/A technical success Decreased tinnitus severity p<0.0001) in patients with specialized care, 6 mo 0% complications	Multiple components to specialized care arm, difficult to determine which of those interventions contributed to improved patient symptoms	Cima et al 2012 [67]
	Chronic tinnitus	Repetitive transcranial magnetic stimulation	Repetitive transcranial magnetic stimulation	1228	Systematic review/ Meta-analysis	100% technical success Decreased tinnitus severity, 1 mo 0% complications	Limited number of studies included in the analysis (29)	Liang et al 2020 [68]
	Chronic tinnitus	Repetitive transcranial magnetic stimulation	Repetitive transcranial magnetic stimulation	233	Systematic review/ Meta-analysis	100% technical success No significant difference between control and treatment patients at 4 mo 0% complications	Limited number of studies used (5)	Meng et al 2011 [69]

Supplemental Figure 2. A standardized template for venous manometry and balloon test occlusion facilitates evaluation of venous causes of pulsatile tinnitus. Each position is numbered (#1-3 for the superior sagittal sinus, #4-18 even numbers for the right transverse sinus, sigmoid sinus, and jugular vein, and #5-19 odd numbers for the left transverse sinus, sigmoid sinus, and jugular vein). At particular positions, in addition to pressure measurements, we can record pulsatile tinnitus scores with and without balloon test occlusion, as indicated.

Name: **MRN:**

Date of documentation:

Last opening pressure, date:

Other demographic comment:

Provocative position(s):
Rotation L, Rotation R, Flexion, Extension, Valsalva

Dominance: Left, Right, Co-Dominant

Fenestration/Duplications: SSS RTS LTS

Superior sagittal sinus

Micro / Guide

Torcular

C2
C3
C4

Right

Transverse sinus

Transverse sigmoid junction

Sigmoid sinus

Jugular bulb

IJV at C1

IJV below C1

R atrium

Left

Transverse sinus

Transverse sigmoid junction

Sigmoid sinus

Jugular bulb

IJV at C1

IJV below C1

Brachiocephalic v.

Venous Drainage

Internal Jugular System 0 1 2 3 4 5

External Jugular System 0 1 2 3 4 5

Suboccipital - Deep Cervical Network 0 1 2 3 4 5

Paravertebral System 0 1 2 3 4 5

Anterior Condylar Network 0 1 2 3 4 5

Parapharyngeal Network 0 1 2 3 4 5

Perimedullary Network 0 1 2 3 4 5

Transosseous/Emissary 0 1 2 3 4 5

Balloon Test Occlusion

Position (R)	↑ ↓	Position (L)	↑ ↓
4		5	
6		7	
10		11	
12		13	
14		15	
R condylar v.		L condylar v.	

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