Original Article

Diagnosis and Management of Barosinusitis: A Systematic Review

Annals of Otology, Rhinology & Laryngology
2023, Vol. 132(1) 50–62

DOI: 10.1177/00034894211072353
journals.sagepub.com/home/aor
SAGE

Tiffany Chen, BA[1], Shivani Pathak, MD[2], Ellen M. Hong, BA[1], Brian Benson, MD[1,3], Andrew P. Johnson, MD[2], and Peter F. Svider, MD[3,4]

Abstract

Objective: To perform a systematic review to investigate the common presenting symptoms of barosinusitis, the incidence of those findings, the methods for diagnosis, as well as the medical and surgical treatment options.

Methods: A review of PubMed/MEDLINE, EMBASE, and Cochrane Library for articles published between 1967 and 2020 was conducted with the following search term: aerosinusitis OR "sinus squeeze" OR barosinusitis OR (barotrauma AND sinusitis) OR (barotrauma AND rhinosinusitis). Twenty-seven articles encompassing 232 patients met inclusion criteria and were queried for demographics, etiology, presentation, and medical and surgical treatments.

Results: Mean age of patients was 33.3 years, where 21.7% were females and 78.3% were males. Causes of barotrauma include diving (57.3%), airplane descent (26.7%), and general anesthesia (0.4%). The most common presentations were frontal pain (44.0%), epistaxis (25.4%), and maxillary pain (10.3%). Most patients received topical steroids (44.0%), oral steroids (28.4%), decongestants (20.7%), and antibiotics (15.5%). For surgical treatment, most patients received functional endoscopic sinus surgery (FESS) (49.6%). Adjunctive surgeries include middle meatal or maxillary antrostomy (20.7%), septoplasty (15.5%), and turbinate surgery (9.1%). The most efficacious medical treatments are as follows: 63.6% success rate with oral steroids (66 treated), 50.0% success rate with topical steroids (102 treated), and 50.0% success rate analgesics (10 treated). For surgical treatments received by greater than 10% of the sample, the most efficacious was FESS (91.5% success rate, 108 treated).

Conclusion: Oral and topical steroids should be first line therapies. If refractory, then functional endoscopic sinus surgery is an effective treatment.

Keywords

barotrauma, sinusitis, sinus squeeze, aerosinusitis, FESS

Introduction

Barotrauma is defined as injury or inflammation that occurs secondary to uncompensated changes in ambient pressure. It most commonly affects the ears, known as "airplane ear," however it can also affect individual or multiple sinuses, known as barosinusitis. Typically, patients will present with severe sudden onset of pain with or without an episode of epistaxis. In rare cases, barosinusitis has presented with meningitis, septal abscess, pneumocephalus, and blindness.[1] The pathophysiology of barosinusitis has been described as early as 1942 by Campbell.[2] The trauma is easily explained by Boyle's law, which states that at a given temperature, volume of gas varies inversely with pressure. Uncompensated changes in air pressure, specifically when a sinus is obstructed either anatomically or secondary to underlying disease, prevents that sinus from communicating with the nasal cavity and equalizing to the surrounding changes in pressure. As a result, gas can either expand within the sinus, resulting in mucosal injury and submucosal hemorrhage, or can create a vacuum seal or "squeeze," resulting in centripetal pulling forces that cause mucosal avulsion.[1]

[1]Hackensack Meridian School of Medicine at Seton Hall University, Nutley, NJ, USA
[2]Department of Otolaryngology – Head and Neck Surgery, University of Colorado, Aurora, CO, USA
[3]Hackensack University Medical Center, Hackensack, NJ, USA
[4]Bergen Medical Associates, Emerson, NJ, USA

Corresponding Author:
Tiffany Chen, BA, Hackensack Meridian School of Medicine, 340 Kingsland Street, Nutley, NJ 07110-6101, USA.
Email: Tiffany.chen@hmhn.org

There have been 2 proposed classification systems. A clinical grading system separates symptoms into 3 grades. Grade 1 involves transient mild discomfort that only lasts for a few hours. Grade 2, patients present with more severe pain lasting up to 24 hours. Objectively, radiographs may show some mucosal thickening. Grade 3 patients present with severe pain that continues for days to weeks and also have objective findings on radiographic imaging of mucosal thickening, air-fluid levels, sinus clouding, or submucosal hemorrhage.[3] Another classification system proposed by Vaezeafshar et al[1] suggests categorizing barosinusitis into acute, recurrent acute, and chronic. Acute barosinusitis is defined as a sudden onset of symptoms and involving only a single sinus. Recurrent acute barosinusitis is defined as having frequent attacks, more than once, that are separated by normal symptom free periods.[1] Vaezeafshar et al found that these patients are more likely to have underlying chronic sinus inflammation or anatomic obstruction. Chronic barosinusitis is more likely to affect those in the aviation and diving occupation and presents as persistence of symptoms between acute episodes.

Although it has been mostly described within aviation and diving literature, barotrauma related injuries to the sinuses have also been found with hyperbaric oxygen therapy, chinook wind exposure, high altitude, Valsalva maneuvers, and anesthesia.[1] Up to 34% of all scuba divers[4] and 25% of pilots[5,6] report sinonasal injury with activity. Various treatment options have been proposed, however, there is no consensus amongst the literature. This systematic review aims to investigate the common presenting symptoms for barosinusitis, the incidence of those findings, the methods for diagnosis, as well as the medical and surgical treatment options.

Methods

The Preferred Reporting Systems for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed for this systematic review.[7] A comprehensive search of PubMed/MEDLINE, EMBASE and Cochrane Library for articles published between 1967 and 2020 was conducted with the following search term: aerosinusitis OR "sinus squeeze" OR barosinusitis OR (barotrauma AND sinusitis) OR (barotrauma AND rhinosinusitis). An initial screen of abstracts was conducted by 2 independent reviewers for relevance and potential inclusion in this review. Full texts were then obtained and comprehensively reviewed by the same authors with conflicts resolved by a third author. References of articles meeting inclusion criteria were also reviewed to ensure all relevant studies were included.

All studies reporting on patients diagnosed with barotrauma to the sinuses detailing patient characteristics, diagnosis, and management were included. Exclusion criteria included articles that were non-English, not relevant, reported on non-human populations, and inability to access full text or extract relevant or patient level data. No contact was made with authors. All studies were assessed for bias with methodological index for non-randomized studies (MINORS) criteria and grading for case reports and case series proposed by Murad et al (Table 1a and b).[8,9] Data was collected on demographics, symptoms, common clinical and radiological findings, as well as medical and surgical management. Tables summarizing the main outcomes were created.

Results

The search yielded 369 articles, of which 118 were duplicates (Figure 1). No other systematic reviews or meta-analyses were identified. Twenty-seven articles encompassing 232 patients met strict inclusion criteria. Using the aforementioned tools to assess risk of bias, the overall quality of evidence was determined to be low.

Of studies with extractable data, the mean age of patients was 33.3 years, where 21.7% were females and 78.3% were males (Table 2). Causes of barotrauma include diving (57.3%), airplane descent (26.7%) and general anesthesia (0.4%). By the classification criteria proposed by Vaezeafshar et al, 77 patients had acute barosinusitis (ABS), 55 had recurrent acute barosinusitis (RABS), and 87 patients had chronic barosinusitis (CBS). One article did not specify the number of patients categorized as RABS and CBS.

The most common presenting manifestations (Table 3) were frontal pain (44.0%), epistaxis (25.4%), maxillary pain (10.3%), rhinorrhea (9.5%), nasal obstruction (8.6%), middle ear equalization difficulty with Valsalva maneuver (6.5%), generalized headache (5.2%). Less than 5% of patients presented with intraorbital pain, facial paresthesia, nausea and vomiting, hearing loss and tinnitus, and lacrimation. Most commonly, CT was the imaging of choice out of studies reporting use of imaging (70.6%). Use of X-ray (25.4%) and MRI (4.0%) were less commonly reported. Of the patients with reported CT imaging results, the frontal sinus was most commonly affected in 58.6% of patients while 22.8% involved the maxillary, 15.5% involved the ethmoid and 6.5% involved the sphenoid.

In terms of medical treatment, most patients received topical steroids (44.0%). Other common treatments include oral steroids (28.4%), decongestants (20.7%) and antibiotics (15.5%). Less commonly, patients were treated with antihistamines (12.1%) and analgesics (4.3%). A total of 52 patients received unspecified medical treatment and 1 did not receive any treatment at all and self-resolved (Table 4a).

In terms of surgical treatment, most patients received functional endoscopic sinus surgery (FESS) involving more than one sinus with or without Draf IIa or III (52.6%), most commonly the ethmoid sinus (86 patients), followed by the maxillary sinus (44), frontal sinus (31), sphenoid sinus (26),

Table 1. (a) MINORS Score.

Study	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to study aim	Loss to follow-up of less than 5%	Prospective calculation of study size	Adequate control group*	Contemporary groups*	Baseline equivalence of groups*	Adequate statistical analyses*	MINORS score
Klingmann et al (2007)[26]	2	2	0	2	2	2	2	0	0	0	0	0	12
Özturk and Bozkurt (2020)[27]	2	2	0	2	2	2	2	0	0	0	0	0	12
Skevas et al (2012)[28]	2	2	0	2	0	2	2	2	0	0	0	0	12
Uzun (2009)[29]	2	2	0	2	2	2	0	0	0	0	0	0	10

*Indicates score for RCT.

(b) Murad et al Scoring for Case Reports and Case Series.

Study	1. Does the patient(s) represent(s) the whole experience of the investigator (centre)?	2. Was the exposure adequately ascertained?	3. Was the outcome adequately ascertained?	4. Alternative causes ruled out?	5. Was there a challenge/rechallenge phenomenon? (less important)	6. Was there a dose–response effect? (less important)	7. Was follow-up long enough for outcomes to occur?	8. Is the case(s) described with sufficient details?	Total score
Patel et al (2021)[30]	1	1	1	0	0	0	1	1	5
Misirovs and Mohamad[14]	0	1	1	0	0	0	1	0	3
Sung et al[18]	1	1	1	1	0	0	1	1	6
Lachkar et al (2016)[31]	1	1	1	0	0	0	1	1	5
Nagatani (2013)[32]	1	1	1	1	0	0	0	1	5
Sanborn et al (2013)[33]	0	1	1	1	0	0	1	1	5
Jeong et al[23] (case report)	1	1	1	1	0	0	1	1	6
Andrews et al (2010)[34]	1	1	1	1	0	0	1	1	6
Murugesan et al (2010)[35]	0	1	1	1	0	0	0	0	3
Bourolias and Gkotsis (2011)[36]	0	1	1	1	0	0	1	1	5
Weitzel et al (2009)[37]	1	1	1	1	0	0	1	1	6
Sharma et al (2007)[38]	1	1	1	1	0	0	0	1	5
Tryggvason et al (2006)[39]	1	1	1	1	0	0	1	1	6
Mahabir et al[20]	1	1	1	1	0	0	1	1	6
Segev et al[24]	1	1	1	1	0	0	1	1	6
Parell and Becker (2000)[40]	1	1	1	1	0	0	1	1	6
Singletary and Reilly[16]	0	1	1	1	0	0	0	1	4
Rodenberg[13]	1	1	1	1	0	0	0	1	5
Weissman et al[3]	0	1	1	1	0	0	1	1	5
Salvinelli et al (2005)[41]	1	1	1	1	0	0	1	1	6
O'Reilly et al (1996)[42]	1	1	1	1	0	0	1	1	6
Fagan et al[17]	1	1	1	1	0	0	1	1	6
Boston et al[25]	1	1	1	1	0	0	1	1	6

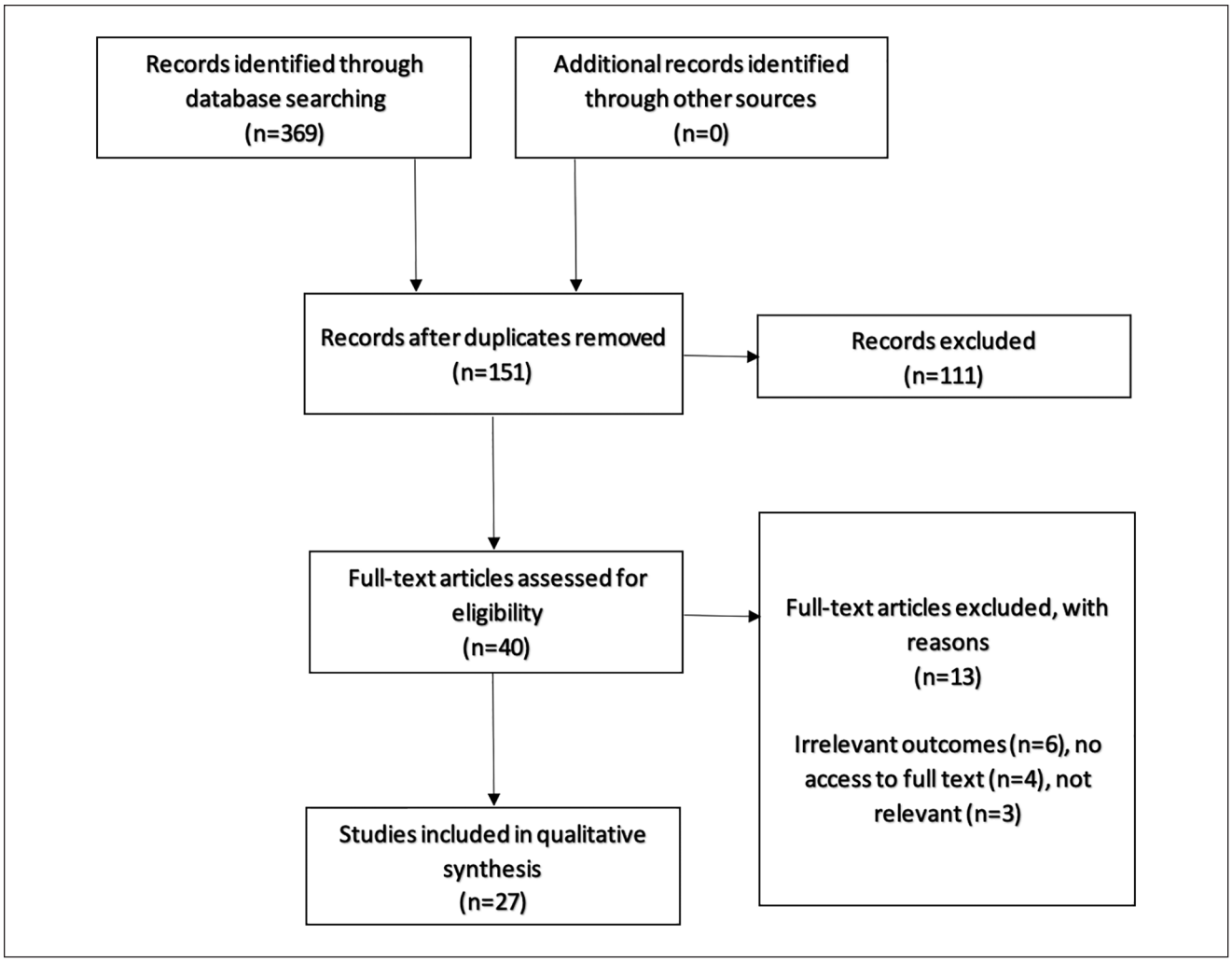

Figure 1. Search method.

and frontoethmoidal recess (19). Some patients also received septoplasty (15.5%) and turbinate surgery (9.1%) as adjunctive therapies. For rare presentations, less than 3% of patients each underwent sinus washout with or without debridement, aspiration, incision and drainage, balloon tuboplasty, balloon sinuplasty, craniotomy, isolated uncinectomy, and endoscopic modified Lothrop procedure (EMLP) (Table 5a).

Efficacy of treatment was defined as reduction or improvement in symptoms at time of latest follow up or if considered successful by the original study. The efficacy of medical treatments (Table 4b) are as follows: 63.6% success rate with oral steroids (66 treated), 50.0% success rate with topical steroids (102 treated), and 50.0% success rate analgesics (10 treated), 37.5% success rate with decongestants (48 treated), 13.9% success rate with antibiotics (36 treated) and 0% success rate with antihistamines (28 treated). The efficacy for surgical treatments for rare presentations were calculated as 100% success rate in the following: craniotomy (3 treated), incision and drainage (2 treated), aspiration (1 treated) and EMLP (1 treated). FESS of more than one sinus with or without Draf IIa or III had a success rate of 92.6% (116 treated). Septoplasty, turbinate surgery and balloon tuboplasty were sometimes performed in conjunction with FESS and not in isolation for treatment of barosinusitis, therefore their success rates were not calculated (Table 5b).

A subgroup analysis of treatments and efficacy was performed based on the classification system proposed by Vaezeafshar et al for treatments received by at least 10% of patients in that category. Out of the 27 patients receiving specified treatments that met criteria for acute barosinusitis (ABS), 63.0% received decongestants, 29.6% received antibiotics, 29.6% received analgesics, and 18.5% underwent FESS. Fifty-two patients categorized as ABS received undefined medical treatment. The efficacy for treatments

Table 2. Demographics and Causes of Barotrauma.

Study	Number of patients	Mean age	Male	Female	Causes of barotrauma		
					Diving	Airplane	General anesthesia
Özturk and Bozkurt (2020)[27]	25	34	21	4	25		
Patel et al (2021)[30]	1	13	1		1		
Misirovs and Mohamad[14]	1	27		1		1	
Sung et al[18]	1	30	1			1	
Boston et al[25]	9	34	8	1		9	
Lachkar et al (2016)[31]	1	26			1		
Nagatani (2013)[32]	1	26		1		1	
Sanborn et al (2013)[33]	1	81	1			1	
Jeong et al[23]	1	18	1		1		
Skevas et al (2012)[28]	40	45	29	11	40		
Andrews et al (2010)[34]	1	35		1		1	
Murugesan et al (2010)[35]	1	21	1		1		
Bourolias and Gkotsis (2011)[36]	2	33	2		1		
Weitzel et al (2009)[37]	1	36	1			1	
Uzun (2009)[29]	12	25	n/a	n/a	12		
Sharma et al (2007)[38]	1	26		1		1	
Tryggvason et al (2006)[39]	1	20	1		1		
Mahabir et al[20]	1	68	1			1	
Segev et al[24]	1	43	1			1	
Parell and Becker (2000)[40]	2	37.5	2				
O'Reilly et al (1996)[42]	39	n/a	n/a	n/a		39	
Singletary and Reilly[16]	1	25	1			1	
Rodenberg[13]	1	23	1			1	
Fagan et al[17]	50	n/a	n/a	n/a	50		
Weissman et al[3]	3	23	3			3	
Klingmann et al (2007)[26]	33	37	25	8			
Salvinelli et al (2005)[41]	1	47	n/a	n/a			1
Total	232	33.3	101	28	133	62	1

of ARS were calculated as 94.1% for decongestants (17 treated), 80.0% for FESS (5 treated), and 62.5% for antibiotics (8 treated) and analgesics (8 treated) each.

Out of the 55 patients receiving specified treatments that met criteria for recurrent acute barosinusitis (RABS), 98.2% underwent FESS, 25.5% received decongestants, 25.5% received steroid nasal spray, 23.6% received antibiotics, and 23.6% received antihistamines. The efficacy for treatments of RABS were calculated as 90.7% for FESS (54 treated), 7.1% for decongestants (14 treated), 0% each for antibiotics (13 treated), antihistamine (13 treated), and steroid nasal spray (14 treated).

Of the 87 patients receiving specified treatments that met criteria for chronic barosinusitis (CBS), 100% received steroid nasal spray, 72.4% received oral steroids, 51.7% received FESS and 16.1% each received antibiotics, decongestants, and antihistamines. The efficacy for treatments of CBS were calculated as 100% for FESS (45 treated), 65.1% for oral steroids (63 treated), 58.6% for steroid nasal spray (87 treated), and 0% each for decongestants (14 treated), antibiotics (14 treated), and antihistamine (14 treated).

Lastly, 14 patients experienced complications. These included stenosis in 3 patients, abscess in 2, hematoma in 2, Potts puffy tumor in 1, wound dehiscence at fistula in 1, extradural pneumo- and muco-cephalus in 1, meningitis in 1, dense adhesions in 1, postoperative maxillary sinusitis in 1 and opacification in 1.

Discussion

Barosinusitis has been well described since the early 1900s.[10] It is defined as acute or chronic inflammation of paranasal sinuses produced by barometric pressure differentials between the atmosphere and the air within the sinuses. Barosinusitis occurs via 1 of 3 mechanisms: squeeze, reverse squeeze, or mixed phenomenon. Squeeze occurs during descent, which causes an increase in atmospheric pressure. Typically, the sinus ostia should be open to the nasal

Table 3. Manifestations.

Study	Nasal obstruction	Rhinorrhea	Frontal pain	Maxillary pain	Ethmoidal pain	General HA	Facial paresthesia	N/V	Epistaxis	Middle ear equalization difficulty w/valsalva	Hearing & tinnitus	Eye tearing	Nasal septal deviation
Özturk and Bozkurt (2020)[27]	20	20	17	12		5			17	15	2		
Patel et al (2021)[30]			1					1				1	1
Misirovs and Mohamad[14]		1		1								1	1
Sung et al[18]		1	1										
Boston et al[25]													
Lachkar et al (2016)[31]			1						1				
Nagatani (2013)[32]			1										
Sanborn et al (2013)[33]				1									
Jeong et al[23]						1			1				1
Skevas et al (2012)[28]													
Andrews et al (2010)[34]			1										
Murugesan et al (2010)[35]						1		1					
Bourolias and Gkotsis (2011)[36]						2		1					
Weitzel et al (2009)[37]			1										
Uzun (2009)[29]			US*	US					4				
Sharma et al (2007)[38]				1			1						
Tryggvason et al (2006)[39]						1							
Mahabir et al[20]						1		1					
Segev et al[24]			1										1
Parell and Becker (2000)[40]						1	1						
O'Reilly et al (1996)[42]			48	6					6				
Singletary and Reilly[16]			1									1	
Rodenberg[13]			1										
Fagan et al[17]			34	3	3				29				
Weissman et al[3]			3										
Klingmann et al (2007)[26]													
Salvinelli et al (2005)[41]			1	1			1		1				
Total	20	22	112	25	3	12	3	4	59	15	2	3	4

US, unspecified.

Table 4. (a) Medical Treatments Received.

	Antibiotics	Decongestant	Analgesic	Antihistamine	Topical steroids	Oral steroids	Unspecified	No treatment
Özturk and Bozkurt (2020)[27]	25	25		25	25			
Patel et al (2021)[30]	1		1	1				
Misirovs and Mohamad[14]				1	1			
Sung et al[18]	1		1					
Boston et al[25]								
Lachkar et al (2016)[31]	1		1			1		
Nagatani (2013)[32]		1	1					
Sanborn et al (2013)[33]								
Jeong et al[23]	1		1					
Skevas et al (2012)[28]					40	40		
Andrews et al (2010)[34]	1	1			1	1		
Murugesan et al (2010)[35]								
Bourolias and Gkotsis (2011)[36]	2	2	2					
Weitzel et al (2009)[37]	1	1		1	1	1		
Uzun (2009)[29]	1	12						
Sharma et al (2007)[38]					1			
Tryggvason et al (2006)[39]	1*							
Mahabir et al[20]								
Segev et al[24]								1
Parell and Becker (2000)[40]							2	
O'Reilly et al (1996)[42]								
Singletary and Reilly[16]		1	1					
Rodenberg[13]	1	1	1					
Fagan et al[17]							50	
Weissman et al[3]		3						
Klingmann et al (2007)[26]					33	23		
Salvinelli et al (2005)[41]		1	1					
Total	36	48	10	28	102	66	52	1

*For presumed meningitis.

(b) Medical Treatment Success Rate.

Study	Antibiotics	Decongestant	Analgesic	Antihistamine	Topical steroids	Oral steroids
Özturk and Bozkurt (2020)[27]						
Patel et al (2021)[30]						
Misirovs and Mohamad[14]						
Sung et al[18]						
Boston et al[25]						
Lachkar et al (2016)[31]	1					1
Nagatani (2013)[32]		1				
Sanborn et al (2013)[33]						
Jeong et al[23]						
Skevas et al (2012)[28]					18	18
Andrews et al (2010)[34]						
Murugesan et al (2010)[35]						
Bourolias and Gkotsis (2011)[36]	2	2	2			
Weitzel et al (2009)[37]						
Uzun (2009)[29]	1	11				
Sharma et al (2007)[38]						
Tryggvason et al (2006)[39]						
Mahabir et al[20]						
Segev et al[24]						
Parell and Becker (2000)[40]						
O'Reilly et al (1996)[42]						
Singletary and Reilly[16]		1	1			
Rodenberg[13]	1	1	1			
Fagan et al[17]						
Weissman et al[3]		1				
Klingmann et al (2007)[26]					33	23
Salvinelli et al (2005)[41]		1	1			
Total	5	18	5	0	51	42
Success rate (%) = # success/# treated	13.9	37.5	50.0	0	50.0	63.6

Table 5. (a) Surgical Treatments Received.

Study	FESS																		
	Maxillary	Ethmoidal	Frontoethmoid recess	Frontal	Sphenoidal	Uncinectomy	Ethmoidectomy	Sinus washout +/− debridement	Aspiration	I&D	Septoplasty	Turbinate surgery	Balloon tuboplasty	Craniotomy	Middle meatal or maxillary antrostomy	Balloon sinuplasty	Draf IIa or III	EMLP
Özturk and Bozkurt (2020)[27]	26	21	18	11	7		3				13	15	2					
Patel et al (2021)[30]				1			1			1	1				1			
Misirovs and Mohamad[14]						1									1			
Sung et al[18]	1			1										1				
Boston et al[25]		8			8		9								9		4	
Lachkar et al (2016)[31]								1										
Nagatani (2013)[32]																		
Sanborn et al (2013)[33]	1							1										
Jeong et al[23]					1				1	1	1							
Skevas et al (2012)[28]	16	21		11	4						9							
Andrews et al (2010)[34]		1			1										1	1	1	
Murugesan et al (2010)[35]														1				
Bourolias and Gkotsis (2011)[36]																		
Weitzel et al (2009)[37]			1		1												1	1*
Uzun (2009)[29]															33			
Sharma et al (2007)[38]	1														1			
Tryggvason et al (2006)[39]																		
Mahabir et al[20]														1				
Segev et al[24]																		
Parell and Becker (2000)[40]							2								2			
O'Reilly et al (1996)[42]		35			4						12	6						
Singletary and Reilly[16]																		
Rodenberg[13]																		
Fagan et al[17]																		
Weissman et al[3]				2														
Klingmann et al (2007)[26]																		
Salvinelli et al (2005)[41]																		
Total	44	86	19	25	26	1	15	2	1	2	36	21	2	3	15	1	6	1

*(+ stent + fibroblast inhibitor).

(b) Surgical Treatment Success Rate.

Study	FESS	Ethmoidectomy	Sinus washout +/−debridement	Aspiration	I&D	Septoplasty	Turbinate surgery	Balloon tuboplasty	Craniotomy	Middle or maxillary meatal antrostomy	Balloon sinoplasty	Draf IIa or III	EMLP
Özturk and Bozkurt (2020)[27]	25	3				NR	NR	NR					
Patel et al (2021)[30]	1	1			1	1							
Misirovs and Mohamad[14]	1									1			
Sung et al[18]	1								1				
Boston et al[25]	6	9										4	
Lachkar et al (2016)[31]													
Nagatani (2013)[32]													
Sanborn et al (2013)[33]	1		1										
Jeong et al[23]	1			1	1	1							
Skevas et al (2012)[28]	21												
Andrews et al (2010)[34]	1											1	
Murugesan et al (2010)[35]									1				
Bourolias and Gkotsis (2011)[36]													
Weitzel et al (2009)[37]													1*
Uzun (2009)[29]													
Sharma et al (2007)[38]	1									1			
Tryggvason et al (2006)[39]													
Mahabir et al[20]									1				
Segev et al[24]													
Parell and Becker (2000)[40]		2								2			
O'Reilly et al (1996)[42]	37					NR	NR						
Singletary and Reilly[16]													
Rodenberg[13]													
Fagan et al[17]													
Weissman et al[3]	2												
Klingmann et al (2007)[26]	10												
Salvinelli et al (2005)[41]													
Total	108	15	1	1	2	—	—	—	3	4	0	5	1
Success rate (%) = # success/# treated	91.5	100.0	50.0	100.0	100.0	—	—	—	100.0	73.3	0	83.3	100.0

Abbreviations: EMLP, endoscopic modified Lothrop procedure; FESS, functional endoscopic sinus surgery; general HA, general headache; I&D, incision and drainage; n/v, nausea and vomiting; RCT, randomized control trial; NR, not reported.

cavities, allowing for equalization of pressures. However, in the presence of an anatomical obstruction of the natural drainage pathways, the sinuses would not be able to equalize pressure. This further results in a negative pressure or squeeze effect within the affected sinus cavity, causing mucosal edema, avulsion, and/or submucosal hemorrhage. During ascent, the opposite occurs, and ambient pressures decrease. If the sinuses cannot equalize pressures during ascent, the pressure within the sinuses increases resulting in expansile compression injury of the mucosa against the bony walls of the sinuses. Squeeze or descent injury is almost 2 times more common than reverse squeeze or ascent injury. There can also be mixed injury to the mucosa with both ascent and descent.[11-14]

Epidemiology

In this review, barosinusitis occurred as a result of either diving, airplane descent or general anesthesia and presented more frequently in males compared to females. Diving was a cause of barotrauma to the sinuses 2.1 times more often than airplane descent. This may be attributed to the tendency for patients to experience greater changes in pressure at faster speeds, which translates to less time for pressure equilibration in the sinuses, in diving as opposed to airplane descent. The contrasting physical properties of water and air also explain this difference: air is compressible and therefore requires greater changes in altitude to cause similar changes in pressure as compared to water, which is non-compressible.[1] Since diving was more common than airplane descent as a cause of barosinusitis of the included studies, the 3.6 to 1 male predominance in this review may be due to a greater number of male divers that are certified in diving. Additionally, one study performed in Norway found that female divers engage in a lower total number of dives and dives that are shallower in depth and lasting shorter periods of time than the male divers.[15]

There was only one cause of barosinusitis in the literature that is attributed to the result of general anesthesia. Other rarer causes reported in the literature include hyperbaric oxygen therapy and Chinook wind. These studies were not a part of this review as there were no patient outcomes reported.

Presentation

Patients most commonly present with severe sudden onset pain that is typically unilateral and over the affected sinus.[1,14,16,17] Our review supports this finding. The most common presentation amongst our patients was frontal pain, seen in 37% of patients. The second most common reported symptom is epistaxis, which was seen in up to 21 % of our patients. Other rare presentations have been reported within the literature, such as blurry vision and photophobia,[13] brain abscess/cerebral empyema[18,19] pneumocephalus,[20,21] blindness, paresthesias,[22] and septal abscess.[23]

Although barosinusitis is largely a clinical diagnosis, objective findings on imaging can assist with diagnosis. Findings, however, are not consistent amongst patients even with similar symptoms. In the literature, mucosal thickening of the maxillary sinus on CT or MRI is most commonly seen, followed by the frontal, ethmoid, and sphenoid sinuses. In contrast, CT findings in this review showed that the frontal sinus is the most commonly involved. There may also be signs of a submucosal hemorrhage, which is categorized as an non-enhancing lesion that is hyperintense on T1 and T2 MRI.[24] Differential for these types of lesions include mucoceles or cholesterol granulomas and as such the diagnosis of barosinusitis should be clinically based.

Treatment

Treatment depends on presentation, however, usually begins initially with medical management followed by surgery for refractory cases, complex presentations, and/or if symptoms are limiting a patient's career. For acute barosinusitis, patients are most commonly started on analgesics, topical steroids, oral steroids, oral antibiotics, topical antihistamines, and/or topical decongestants prior to the consideration of surgery. Of the options available for medical management, we found a 94.1% success rate with the use of topical decongestants in patients with ABS. FESS in this subgroup was curative in 80%. For RABS, topical or medical therapy provided little benefit, whereas FESS was curative in 90.7%. Although in this subgroup, medical treatments were often used in conjunction, symptom relief was not obtained until surgical intervention was pursued. For chronic barosinusitis, FESS is the treatment of choice with success reported as high as 100%.

Given the complication rates of both anesthesia and surgery, for simple acute cases, it is preferred to begin with medical therapy, specifically topical decongestants. Surgery should be discussed for refractory acute, recurrent acute, or chronic cases. However, should barosinusitis initially present with a complication such as septal or intracranial abscess, immediate decompression is warranted. Another instance in which surgery can be considered first line therapy is with those in the aviation and diving industry whose symptoms are limiting their ability to continue working. A review found that complete FESS +/− DRAF IIa or III resolved symptoms in 100% of cases and allowed patients to return to work without any evidence of recurrent symptoms.[25]

In patients at higher risk of developing barosinusitis, such as those with underlying sinonasal inflammation or anatomical obstruction who actively undergo ambient pressure changes, there is some data to suggest medical therapy

prior to undergoing high risk activities may prevent the development of barotrauma. Within the otic literature, administration of 120 mg of pseudophedrine 30 minutes prior to a flight revealed a 52% relative risk reduction in the development of otic barotrauma, whereas administration of oxymetazoline nasal spray revealed a 10% relative risk reduction. There have been no clinical trials evaluating the benefit of medical therapies in the prevention of barosinusitis.

Limitations

This article provides a thorough evidence-based review of the existing literature encompassing management in patients with barosinusitis. Nevertheless, there were some limitations with the study and its design. Inherent to the nature of systematic reviews, the sample of literature utilized for this study may not be comprehensive. Additionally, the results in this study came from studies available in the English language between 1967 and 2020, which may further a potential selection bias. The difference in dosages between various therapeutic agents may have impacted the study outcomes in assessing improvement in otologic symptoms. To mitigate these concerns, treatment efficacy was defined as a reduction or improvement in symptoms or determined to be successful by the original study at the latest follow up. Additionally, the overall quality of evidence of this study was low as the studies included in this review consisted of only case reports and case series. Despite these limitations, this is the first systematic review to investigate the management of barosinusitis and provide guidelines for clinical practice.

Conclusion

Barosinusitis often occurs as a result of either diving or airplane descent and commonly presents with frontal pain and epistaxis. For mild or initial presentations of barosinusitis, it is important to consider the use of medical therapy, that is, oral and topical steroids, initially as there is a vast symptomatic improvement in the majority of patients. For patients with recurrent acute or chronic barosinusitis and those undergoing repetitive ambient pressure changes, FESS will provide the most consistent symptomatic relief.

Author Contributions

Tiffany Chen: data collection, table and figure design, manuscript writing, and critical revision. Shivani Pathak: manuscript writing and critical revision. Ellen M. Hong: data collection, table and figure design. Brian Benson: conceptualization, critical revision. Andrew P. Johnson: conceptualization, critical revision. Peter F. Svider: conceptualization, data collection, critical revision.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Tiffany Chen https://orcid.org/0000-0001-9797-6920
Peter F. Svider https://orcid.org/0000-0001-5791-9585

References

1. Vaezeafshar R, Psaltis AJ, Rao VK, Zarabanda D, Patel ZM, Nayak JV. Barosinusitis: comprehensive review and proposed new classification system. *Allergy Rhinol (Providence)*. 2017;8(3):109-117. doi:10.2500/ar.2017.8.0221
2. Campbell PA. Aerosinusitis—cause, course and treatment. *Ann Otol Rhinol Laryngol*. 1944;53:291-301.
3. Weissman B, Green RS, Roberts PT. Frontal sinus barotrauma. *Laryngoscope*. 1972;82(12):2160-2168. doi:10.1288/00005537-197212000-00003
4. Taylor DM, O'Toole KS, Ryan CM. Experienced scuba divers in Australia and the United States suffer considerable injury and morbidity. *Wilderness Environ Med*. 2003;14(2):83-88. doi:10.1580/1080-6032(2003)014[0083:esdiaa]2.0.co;2
5. Rosenkvist L, Klokker M, Katholm M. Upper respiratory infections and barotraumas in commercial pilots: a retrospective survey. *Aviat Space Environ Med*. 2008;79(10):960-963. doi:10.3357/asem.2287.2008
6. Ulanovski D, Barenboim E, Raveh E, Grossman A, Azaria B, Shpitzer T. Sinusitis in pilots of different aircraft types: is allergic rhinitis a predisposing factor? *Am J Rhinol*. 2008;22(2):122-124. doi:10.2500/ajr.2008.22.3158
7. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ*. 2009;339:b2700. doi:10.1136/bmj.b2700
8. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg*. 2003;73(9):712-716. doi:10.1046/j.1445-2197.2003.02748.x
9. Murad MH, Sultan S, Haffar S, Bazerbachi F. Methodological quality and synthesis of case series and case reports. *BMJ Evid Based Med*. 2018;23(2):60-63. doi:10.1136/bmjebm-2017-110853
10. Marchoux ENH. Influence de l'intégrité de la muqueuse phono-pharyngienne sur l'aptitude des aviateurs au vol. *Compt Ren Soc de biol*. 1919;82:668-673.
11. Weitzel EK, McMains KC, Wormald P-J. Comprehensive surgical management of the aerosinusitis patient. *Curr Opin Otolaryngol Head Neck Surg*. 2009;17(1):11-17. doi:10.1097/moo.0b013e32831b9caa
12. Weitzel EK, McMains KC, Rajapaksa S, Wormald P-J. Aerosinusitis: pathophysiology, prophylaxis, and management in

passengers and aircrew. *Aviat Space Environ Med*. 2008;79(1): 50-53. doi:10.3357/asem.2203.2008
13. Rodenberg H. Severe frontal sinus barotrauma in an airline passenger: a case report and review. *J Emerg Med*. 1988; 6(2):113-115. doi:10.1016/0736-4679(88)90149-7
14. Misirovs R, Mohamad S. Reverse squeeze maxillary sinus barotrauma. *Ear Nose Throat J*. 2020;99(1):NP9-NP10. doi: 10.1177/0145561319825556
15. Irgens Å, Troland K, Grønning M. Female professional divers. Similarities and differences between male and female professional divers. *Int Marit Health*. 2017;68(1):60-67. doi:10.5603/IMH.2017.0010
16. Singletary EM, Reilly JF. Acute frontal sinus barotrauma. *Am J Emerg Med*. 1990;8(4):329-331. doi:10.1016/0735-6757(90)90088-h
17. Fagan P, McKenzie B, Edmonds C. Sinus barotrauma in divers. *Ann Otol Rhinol Laryngol*. 1976;85(1 Pt 1):61-64. doi:10.1177/000348947608500110
18. Sung J, Kwon O, Kim D, Kim K. Bilateral subdural empyemas with meningitis secondary to acute barosinusitis. *Eur Ann Otorhinolaryngol Head Neck Dis*. 2018;135(6):457-459. doi:10.1016/j.anorl.2018.03.006
19. Buisson P, Darsonval V, Dubin J. Sinus infection and diving (a case of cerebral empyema). *Rev Laryngol Otol Rhinol (Bord)*. 1990;111(2):141-143.
20. Mahabir RC, Szymczak A, Sutherland GR. Intracerebral pneumatocele presenting after air travel. *J Neurosurg*. 2004;101(2):340-342. doi:10.3171/jns.2004.101.2.0340
21. Goldmann RW. Pneumocephalus as a consequence of barotrauma. *JAMA*. 1986;255(22):3154-3156.
22. Murrison AW, Smith DJ, Francis TJ, Counter RT. Maxillary sinus barotrauma with fifth cranial nerve involvement. *J Laryngol Otol*. 1991;105(3):217-219. doi:10.1017/s0022215100115415
23. Jeong JH, Kim K, Cho SH, Kim KR. Sphenoid sinus barotrauma after scuba diving. *Am J Otolaryngol*. 2012;33(4): 477-480. doi:10.1016/j.amjoto.2011.10.017
24. Segev Y, Landsberg R, Fliss DM. MR imaging appearance of frontal sinus barotrauma. *AJNR Am J Neuroradiol*. 2003;24(3):346-347.
25. Boston AG, McMains KC, Chen PG, Weitzel EK. Algorithm for management of the refractive aerosinusitis patient. *Mil Med*. 2018;183(7-8):e246-e250. doi:10.1093/milmed/usx222
26. Klingmann C, Praetorius M, Baumann I, Plinkert PK. Otorhinolaryngologic disorders and diving accidents: an analysis of 306 divers. *Eur Arch Otorhinolaryngol*. 2007 Oct;264(10):1243-51. doi: 10.1007/s00405-007-0353-6. Epub 2007 Jul 17. PMID: 17639445.
27. Öztürk Ö, Bozkurt Z. The surgical management of recurrent acute and chronic barosinusitis in sports self-contained underwater breathing apparatus (scuba) divers. *Eur Arch Otorhinolaryngol*. 2020 Sep;277(9):2475-2484. doi: 10.1007/s00405-020-06034-3. Epub 2020 May 14. PMID: 32409859.
28. Skevas T, Baumann I, Bruckner T, Clifton N, Plinkert PK, Klingmann C. Medical and surgical treatment in divers with chronic rhinosinusitis and paranasal sinus barotrauma. *Eur Arch Otorhinolaryngol*. 2012 Mar;269(3):853-60. doi: 10.1007/s00405-011-1742-4. Epub 2011 Sep 8. PMID: 21901337.
29. Uzun C. Paranasal sinus barotrauma in sports self-contained underwater breathing apparatus divers. *J Laryngol Otol*. 2009 Jan;123(1):80-4. doi: 10.1017/S0022215108002739. Epub 2008 May 23. PMID: 18501035.
30. Patel A, Vuppula S, Hayward H, Lakhani A, Lighter J. A Case of Pott's Puffy Tumor Associated With Barosinusitis From Scuba Diving. *Pediatr Emerg Care*. 2021 Jan 1;37(1):e51-e54. doi: 10.1097/PEC.0000000000001657. PMID: 30601343; PMCID: PMC7774810.
31. Lachkar A, Aabach A, Elayoubi F, Ghailan R. Barotraumatisme du sinus frontal à propos d'un cas et revue de la littérature [Frontal sinus barotrauma: about a case and review of the literature]. *Pan Afr Med J*. 2016 Jul 27;24:272. French. doi: 10.11604/pamj.2016.24.272.5742. PMID: 28154627; PMCID: PMC5267904.
32. Nagatani K. Two reports of flight-related headache. *Aviat Space Environ Med*. 2013 Jul;84(7):730-3. doi: 10.3357/asem.3253.2013. PMID: 23855070.
33. Sanborn MR, Nasrallah I, Stanton DC, Stiefel MF, Hurst RW, Pukenas BA. Acquired arteriovenous fistula associated with traumatic oroantral fistula: endovascular treatment. *Head Neck*. 2013 May;35(5):E138-41. doi: 10.1002/hed.21978. Epub 2012 Jan 31. PMID: 22290759.
34. Andrews JN, Weitzel EK, Eller R, McMains CK. Unsuccessful frontal balloon sinuplasty for recurrent sinus barotrauma. *Aviat Space Environ Med*. 2010 May;81(5):514-6. doi: 10.3357/asem.2716.2010. PMID: 20464821.
35. Murugesan C, Powell M, Khayal HB. Sinus barotrauma leading to extradural muco-pneumocephalus. *Br J Neurosurg*. 2010 Feb;24(1):80-1. doi: 10.3109/02688690903506069. PMID: 20158359.
36. Bourolias C, Gkotsis A. Sphenoid sinus barotrauma after free diving. *Am J Otolaryngol*. 2011 Mar-Apr;32(2):159-61. doi: 10.1016/j.amjoto.2009.10.005. Epub 2009 Dec 22. PMID: 20022669.
37. Weitzel EK, Flottmann JT, McMains KC. Endoscopic frontal sinus drillout for recurrent barotrauma: a procedure to save a pilot's career. *Aviat Space Environ Med*. 2009 Jul;80(7):660-2. doi: 10.3357/asem.2513.2009. PMID: 19601511.
38. Sharma N, De M, Pracy P. Recurrent facial paraesthesia secondary to maxillary antral cyst and dehiscent infraorbital canal: case report. *J Laryngol Otol*. 2007 Jun;121(6):e6. doi: 10.1017/S0022215107007785. Epub 2007 Apr 20. PMID: 17445308.
39. Tryggvason G, Briem B, Guomundsson O, Einarsdóttir H. Sphenoid sinus barotrauma with intracranial air in sella turcica after diving. *Acta Radiol*. 2006 Oct;47(8):872-4. doi: 10.1080/02841850600771494. PMID: 17050370.
40. Parell GJ, Becker GD. Neurological consequences of scuba diving with chronic sinusitis. *Laryngoscope*. 2000 Aug;110(8):1358-60. doi: 10.1097/00005537-200008000-00026. PMID: 10942141.
41. Salvinelli F, Rinaldi V, D'Ascanio L. Paranasal sinus barotrauma in general anesthesia: special attention. *J Clin Anesth*. 2005 Jun;17(4):323. doi: 10.1016/j.jclinane.2004.12.012. PMID: 15950861.
42. O'Reilly BJ, Lupa H, Mcrae A. The application of endoscopic sinus surgery to the treatment of recurrent sinus barotrauma. *Clin Otolaryngol Allied Sci*. 1996 Dec;21(6):528-32. doi: 10.1111/j.1365-2273.1996.tb01104.x. PMID: 9118575.