Diagnostic approaches to and management options for patulous eustachian tube

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ABSTRACT

Objectives: To systematically review the literature and to summarize all evidence related to the diagnosis and management of patulous eustachian tube.

Methods: The present study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Results: Overall, 59 articles were retrieved and included in the analysis. Studies investigating treatments enrolled 1279 patients collectively, with follow-up duration varying from few days and up to 2 years. Eight studies reported medical treatments with intranasal saline instillation as the most frequently studied option. Other studies reported various surgical treatments varying from simple tympanostomy to invasive procedures targeting the orifice of the ET or the anatomical features surrounding it. In addition, 10 studies including 367 subjects investigated different diagnostic methods.

Conclusion: Currently, there is a wide spectrum of diagnostic and therapeutic interventions with minimal clinical efficacy, a persistent lack of systematic guidelines, and several gaps in previous research endeavours.

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Keywords: patulous eustachian tube, management, diagnosis

Patulous eustachian tube (PET), a benign, largely idiopathic, condition, was first described in 1867. It has adverse effects that can markedly affect quality of life such as abnormal autophony, breathing, or hearing. Several factors have been reported to be causative, including pregnancy, neurological disorders, weight loss and radiotherapy, and some medications including oral contraceptives and diuretics. In terms of pathophysiology, all stressors that distort normal closure
of the eustachian tube (ET) during the resting state can result in PET. This includes conditions affecting the elasticity, surface tension, and opening pressure of the ET.  

According to experts, there is currently a lack of universal consensus regarding symptom scores, tests, and guidelines to diagnose PET. Meanwhile, the diagnostic approach relies primarily on clinical assessment of the presenting symptoms. This non-systematic approach makes the identification of these cases challenging. Symptoms that should raise suspicion include aural fullness, popping, and discomfort or pain, in addition to autophony of breathing or voice. Signs include tympanic membrane retraction and signs of negative middle ear pressure. Further studies have been recommended to enhance the diagnostic approach to this condition.

Despite the modest rarity of PET and the hurdles to diagnose, it also represents a challenging condition for patients and clinicians due to limited therapeutic options. Current approaches vary depending on the severity of symptoms and range from informative reassurance to invasive interventions. Some cases may need combined or surgical treatment such as those with no clinical improvement and persistent movement of the tympanic membrane. To date, there have been limited research papers with variable outcome measures and no definite recommendations that outline a precise evidence-based, patient-centered therapeutic guideline.

Given the insufficient diagnostic and therapeutic guidelines, we aim to systematically review the literature and to summarize all evidence related to the diagnosis and management of PET.

**Methods.** This study has followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The study protocol was applied for recording in PROSPERO. Provided the nature of the present study (example, systematic review), requirements for ethics review were waived.

Any primary study that reported or investigated diagnostic approaches or management options for PET were included. There were no restrictions regarding different populations, race, origin, age, ethnicity, language, or publication date. However, letters, editorial comments, theses, book chapters, non-human and experimental studies, and articles with no available full text were excluded. Studies with no extractable data were also excluded.

A computerized systematic search was performed for potentially eligible articles published up to December 2019 using the PubMed, Scopus, ISI Web of Science, Embase, Virtual Health Library (VHL), and Cochrane Central Register of Controlled Trials databases. The search term “patulous eustachian tube” was used to retrieve all relevant articles within the scope of the present study. A manual inspection of the reference section of all competent reports was also considered to recognize any further articles. Search results were retrieved and duplicates were removed using EndNote X7. Two independent reviewers screened potentially relevant articles and included all reports that met the research criteria. Initial screening of titles and abstracts was followed by full-text review. Disagreements were resolved by discussion and consensus between reviewers and among senior researchers.

Three authors independently collected the target outcomes from the eligible articles and filled it into blind Excel sheets. Any discrepancy was resolved by discussion to reach consensus. The extraction form was established using a pilot extraction of a few blindly selected studies. Extracted outcomes comprised demographic informations of the enrolled subjects. In addition, different types of therapeutic and diagnostic approaches, and follow-up period were analyzed. Complete, partial, and non-resolution rates were also compared. Descriptive statistics was carried out and the data were presented as numbers and proportions.

**Results.** The search of the medical literature retrieved 1062 titles (PubMed [n = 204]; VHL [n = 199]; Scopus [n=246], Embase [n=202], ISI Web of Science [n=204], Cochrane Central Register of Controlled Trials [n=7]). After removing 215 duplicates, 847 titles and abstracts were pooled for initial screening (Figure 1). Three reviewers working independently selected 71 articles for full-text screening. After discussion, 25 articles were excluded for irrelevance or improper design, among other reasons (Figure 1). Ultimately, 46 articles were eligible by screening and 13 were identified through the manual search, resulting in 59 articles included for data extraction and analysis.

Of the 59 included studies, 49 investigated treatment options, while 10 described diagnostic approaches. The studies investigating treatments collectively enrolled 1279 patients (1442 ears), with follow-up intervals
varying from 2 weeks to 2 years. Baseline demographics of the enrolled articles are summarized in Table 1.

Medical treatment approach. Eight articles described several non-surgical, intranasal or intratubal treatments (Table 2). Treatment options included guidance to stop sniffing and nasal saline instillation, irrigation using normal saline, potassium iodide, diluted hydrochloric acid, beta chlorobutanol, benzyl alcohol, atropine, 1:4 salicylic acid powder, boric acid powder. The latter was reported in 3 studies enrolling 40 patients, which led to a 100% resolution of PET symptoms.48,53,54 Irritation was the only side effect reported. More recent studies favored the use of topical normal saline with high efficacy (65.7% experienced complete resolution in the study by Ikeda9) and safety (example, no adverse events were reported with the use of saline drops).

Tympanic membrane mass loading approach. Several techniques were used to increase the mass of the tympanic membrane, which is aimed at decreasing its movement and, therefore, potentially improving PET symptoms. In the review, 10 studies reported different means to load the tympanic membrane, which are summarized in Table 3. These techniques included paper patching, loading with ventilation tubes, cartilage chip insertion, myringoplasty, potassium-titanyl-phosphate (KTP) laser, and loading with blue tack. Complete resolution was more frequently reported with the use of blue tack (78.6%) in a sample size of 11 subjects, and paper patching (65.2-76.2%) in 44 patients (56 ears). The side effects of paper patching were limited to mild to moderate discomfort.

Eustachian tube occlusion approach. Ten studies investigated ET occlusion using several modalities including plugging (example, silicon plug, catheter with bone wax, and orifice suturing), cautery, and injections. The outcomes of these reports are elaborated in Table 4. The largest sample size was reported by Kikuchi et al.,14 in which 252 ears were occluded using Kobayashi plug, with a complete resolution rate (CRR) of 64.7% and several reported side effects including tympanic membrane perforation (17.5%) and plug dropping toward the pharyngeal tube (22.6%). Cauterization was reported in 3 case series including 22 patients. Several
Table 1 - Baseline characters of 49 studies reporting treatment of patulous eustachian tube.

| Author/year | Sample size | Age mean (range) | Gender male n (%) | Follow-up period mean (range) months |
|-------------|-------------|------------------|-------------------|-------------------------------------|
| Ali et al\(^{18}\)/2019 | 8 (12 ears) | 52.4 (41-73) | 3 (37.5) | 29-62 |
| Ikeda et al\(^{18}\)/2019 | 28 | 48 | 7 (25) | 6 |
| Kim et al\(^{18}\)/2019 | 23 | 45 (10-79) | 15 (38.5) | 3 |
| Janatová et al\(^{18}\)/2018 | 1 | 38 | 0 | 6 |
| Jeong et al\(^{18}\)/2018 | 11 (14 ears) | 40.8 | 2 (18.2) | 16.4 |
| Jolly et al\(^{18}\)/2018 | 1 | 27 | 0 | 6 weeks |
| Kikuchi et al\(^{18}\)/2017 | 191 (252 ears) | 16-83 | 84 (43.97) | 25.2 (3-168) |
| Endo et al\(^{18}\)/2016 | 31 (44 ears) | 51 (14-88) | 5 (16.1) | NR |
| Mackeith & Bottrell\(^{18}\)/2016 | 11 | 38 (20-67) | 5 (45.5) | 18.3 (3-44) |
| Oh & Kong\(^{18}\)/2016 | 25 (33 ears) | NR | 19 (76.0) | 25.2 (12-40) |
| Si et al\(^{18}\)/2016 | 12 | 34 (23-46) | 4 (33.3) | 6-60 |
| Oh et al\(^{18}\)/2015 | 29 (36 ears) | NR | 16 (55.1) | 19.3 (6-37) |
| Schroeder et al\(^{18}\)/2015 | 20 | 18-96 | 8 (40.0) | 6 |
| Boedts\(^{18}\)/2014 | 21 (33 ears) | 46 (19-72) | 3 (14.2) | 1-2 |
| Brace et al\(^{18}\)/2014 | Cartilage tympanoplasty (10 [11 ears]) | 47.8 | 4 (40.0) | 230 (52-882) days |
| | KTP LM (10 [15 ears]) | 40.7 | 5 (50.0) | 436 (90-719) days |
| Oh et al\(^{18}\)/2014 | 1 | 39 | 1 (100) | 12 |
| Rodrigues et al\(^{18}\)/2014 | 1 | 36 | 0 | 6 |
| Rothenberg et al\(^{18}\)/2014 | 7 | 21-43 | 2 (28.6) | 6-21 |
| Vaezefshar et al\(^{18}\)/2014 | 14 (23 ears) | 53 (14-83) | 4 (28.6) | 17.5 |
| Rothenberg et al\(^{18}\)/2013 | 11 (14 ears) | 37.5 (31-66) | 3 (27.3) | 6 |
| Ikeda et al\(^{18}\)/2011 | 414 | 43.7 (8-85) | 187 (45.2) | NR |
| Kong et al\(^{18}\)/2011 | 2 | 45 and 54 | 2 (100) | 18 and 24 |
| Yanez et al\(^{18}\)/2011 | 11 | 38 (17-54) | 9 (81.8) | 24 |
| Bartlett et al\(^{18}\)/2010 | 14 | 43.57 | 5 (35.7) | 2 years |
| Oshima et al\(^{18}\)/2010 | 52 | 50.7 (16-84) | 27 (51.92) | 2-8 weeks |
| Wolraich & Zur\(^{18}\)/2010 | 1 | 4 | 0 | 18 |
| Olhoff et al\(^{18}\)/2007 | 1 | 45 | 0 | 12 |
| Poe\(^{18}\)/2007 | 11 | NR | 5 (45.4) | 15.8 (3-30) |
| Takano et al\(^{18}\)/2007 | 10 (15 ears) | 31-79 | 3 (30.0) | 13-27 |
| Sato et al\(^{18}\)/2005 | 37 (44 ears) | 10-79 | 17 (45.9) | 38.9 (6-68) |
| Doherty & Slattery\(^{18}\)/2003 | 2 | 38 and 47 | 1 (50.0) | 12 |
| Boudevyns & Claes\(^{18}\)/2001 | 1 | 35 | 1 (100) | 5 weeks-4 and half months |
| DiBartolomeo Henry\(^{18}\)/1992 | 10 | NR | NR | 3 |
| Dyer Jr & McElveen\(^{18}\)/1991 | 1 | 75 | 1 (100) | 2 |
| Chen & Luxford\(^{18}\)/1990 | 46 (60 ears) | (24-84) | 21 (45.6) | 2 weeks |
| Robinson & Robinson\(^{18}\)/1989 | 13 | (24-79) | 4 (30.7) | 3-36 |
| Morita & Matsunaga\(^{18}\)/1988 | 6 (8 ears) | 48 (23-66) | 5 (83.3) | NR |
| Virtanen & Palva\(^{18}\)/1982 | 13 (16 ears) | 45 (20-78) | 8 (61.5) | 24 (2-60) |
| Bluestone & Cantekin\(^{18}\)/1981 | 4 | NR | NR | 36 |
| O’Connor & Shea\(^{18}\)/1981 | 7 | 22-59 | NR | NR |
| Cray et al\(^{18}\)/1979 | 12 | 24-72 | 0 | 12 |
| Ogawa et al\(^{18}\)/1976 | 16 (22 ears) | 20-75 | 7 (43.7) | 1 week-1 year |
| Bhide et al\(^{18}\)/1976 | 1 | 49 | 1 (100) | NR |
| Stroud et al\(^{18}\)/1974 | 3 | 25-75 | 0 | 2 weeks-3 months |
| Misuura\(^{18}\)/1974 | 2 | 38 and 55 | 1 (50.0) | 4-6 |
| Pulec\(^{18}\)/1967 | 26 | NR | NR | NR |
| Thaler & Yanagisawa\(^{18}\)/1966 | 4 | 18-41 | 1 (25.0) | 5-11 |
| Miller\(^{18}\)/1961 | 30 | 20-75 | 12 (40.0) | NR |
| Moore & Miller\(^{18}\)/1951 | 12 | 20-76 | 4 (33.3) | NR |

NR: not reported, KTP: potassium-titanyl-phosphate, LM: laser myringoplasty
techniques and resolution rates are summarized, with otitis media as the only reported side effect. Various types of injectable elements used for inducing ET occlusion are also summarized in Table 4. Those with the largest sample sizes included autologous cartilage injection (33 ears [CRR 27.3%]), soft-tissue bulking agent (26 ears [CRR, 35%]), calcium hydroxyapatite (23 ears [CRR 57-63%]), absorbable gelatin sponge solution (22 ears [CRR 100%]), and Teflon (26 ears [CRR 73.1%]). Otitis media with effusion, epistaxis, tinnitus, and temporomandibular joint discomfort were reported as adverse events post-injection.

**Muscular techniques.** Modulating the tone of the tensor veli palatine muscle can change the patency of

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**Table 2** - Outcomes from 8 studies reporting treatment of patulous eustachian tube through medical approach.

| Author/year        | Study type | Subjects (n) | Treatment                                           | Complete resolution n (%) | Partial resolution n (%) | Adverse events                        |
|--------------------|------------|--------------|-----------------------------------------------------|---------------------------|--------------------------|---------------------------------------|
| Ikeda et al²/2019  | RCS        | 35 (63 ears) | Instruction to stop sniffing + nasal saline instillation | 23 (65.7)                 | NR                       |                                       |
| Oshima et al²/2010 | RCS        | 52           | Nasal saline instillation                           | 24 (46.2)                 | 9 (17.3)                 | NR                                    |
| Boudewyn A/2001    | Case report| 1            | Saturated potassium iodide solution (60g potassium iodide in 42g water), 20 drops daily through tympanostomy tubes | 0                         | 0                        | vertigo and SNHL                       |
| DiBartolomeo Henry³/1992 | PCS    | 10           | Diluted hydrochloric acid + chlorobutanol, benzyl alcohol nasal drops | 8 (80)                    | 2 (20)                   | rhinorrhea and nasal irritation: 2    |
| Morita & Matsunaga⁴/1988 | PCS    | 6 (8 ears)   | Intratubal atropine                                 | 6 (100)                   | NR                       |                                       |
| Bhide et al⁴/1976  | Case report| 1            | 1:4 salicylic: boric acid powder through tympanostomy tubes | 1 (100)                   | NR                       |                                       |
| Miller⁵/1961       | RCS        | 27           | Boric and salicylic acid powder insufflated directly into the torus tubarius | 27 (100)                  | Irritation from solution  |                                       |
| Moore & Miller⁶⁷/1951 | RCS    | 12           | Insufflation of salicylic acid powder and boric acid powder 1:4 proportions | 12 (100)                  | NR                       |                                       |

NR: not reported, SNHL: sensorineural hearing loss, RCS: retrospective case series, PCS: prospective case series

**Table 3** - Outcomes from 10 studies reporting treatment of patulous eustachian tube through tympanic membrane mass loading approach.

| Author/year        | Study type | Subjects (n) | Treatment                                           | Complete resolution n (%) | Partial resolution n (%) | Adverse events                        |
|--------------------|------------|--------------|-----------------------------------------------------|---------------------------|--------------------------|---------------------------------------|
| Kim et al²/2019    | RCS        | 23           | Paper patching over the most mobile quadrants of the tympanic membrane | 15 (65.2)                 | 6 (26.1)                 | NR                                    |
| Jeong et al²/2018  | PCS        | 11 (14 ears)| Tragal cartilage chip insertion via a transcanal approach into ET | 4 ears (28.6)             | 5 ears (35.7)            | NR                                    |
| Si et al⁴⁷/2016    | PCS        | 12           | A myringoplasty with ipsilateral full-thickness tragus cartilage | 12 (100)                  | NR                       |                                       |
| Oh et al²/2014     | RCS        | 29 (36 ears)| TCI                                                 | 22 (62.9)                 | 7 (20.0)                 | OME: 2 ears unilateral mastoiditis: 1 ear |
| Brace et al²/2014  | RCS        | 10 (15)      | Resurface TM with KTP laser                          | 7 (46.7)                  | NR                       |                                       |
| Boedts²/2014       | RCS        | 21 (33 ears)| Paper patch on TM                                   | 16 (76.2)                 | Discomfort with drying patch |                                       |
| Ikeda et al³/2019  | RCS        | 8            | Ventilation tubes                                   | 6 (75.0)                  | 2 (25.0)                 | dislodged tack: 1                     |
| Bartlett et al³⁵/2010 | PCS    | 14           | Mass loading of TM with blue tack                   | 11 (78.6)                 | otorrhoea: 2 persistent perforation: 2 |
| Chen & Luxford¹⁴/1990 | RCS    | 46 (60 ears)| Ventilation tubes                                   | 32 (53.3)                 | AOM: 1                   |                                       |
| Thaler & Yanagisawa⁴²/1966 | RCS | 4            | Short, double flanged, polyethylene tube           | 3 (75.0)                  | 1 (25.0)                 |                                       |

ET: eustachian tube, TM: tympanic membrane, TCI: trans-tympanic catheter insertion, AOM: acute otitis media, OME: otitis media with effusion
NR: not reported, RCS: retrospective case series, PCS: prospective case series, KTP: potassium-titanyl-phosphate
Table 4 - Outcomes from 10 studies reporting treatment of patulous eustachian tube through eustachian tube occlusion.

| Author/year        | Study type | Subjects (n) | Treatment                                                                 | Complete resolution n (%) | Partial resolution n (%) | Adverse events                                                                 |
|--------------------|------------|--------------|---------------------------------------------------------------------------|----------------------------|--------------------------|--------------------------------------------------------------------------------|
| Ikeda et al⁹/2019  | PCS        | 28           | Silicone plug (Kobayashi plug)                                             | 23 (82.1)                 |                          | MEE: 5                                                                           |
|                    |            |              |                                                                           |                            |                          | TMP: 4                                                                           |
|                    |            |              |                                                                           |                            |                          | Tinnitus: 1                                                                     |
|                    |            |              |                                                                           |                            |                          | Ventilation tube placement (prototype 14.8%, new 4.4%) dropped to pharyngeal   |
|                    |            |              |                                                                           |                            |                          | orifice: (prototype 22.6%)                                                     |
| Kikuchi et al⁹/2017| RCS        | 191 (252 ears) | Kobayashi plug in ET (prototype plug-new plug)                           | 163 (64.7)                 | 46 (18.3)                | Symptom recurrence: 2 ears                                                      |
|                    |            |              |                                                                           |                            |                          | TMP: 3 ears                                                                     |
|                    |            |              |                                                                           |                            |                          | OME: 2 ears                                                                     |
| Endo et al⁹/2016   | RCS        | 13 (27 ears)  | trans-tympanic silicone plug insertion                                     | 2 (66.7)                   | 2 ears (33.3)             | Symptom recurrence: 7 ears                                                      |
|                    |            |              |                                                                           |                            |                          | TMP: 3 ears                                                                     |
|                    |            |              |                                                                           |                            |                          | OME: 2 ears                                                                     |
|                    |            |              | ventilation tube insertion                                                | 3 ears (27.3)              | 7 ears (63.6)             | Deviation from treatment: 1 ear                                                 |
| Rotenberg et al⁹/2014| PCS   | 7            | Endoscopic insertion of a 3.5 cm shim (trimmed irrigation catheter with bone wax) sutured into the eustachian tube in patients who failed ET suture ligation | 6 (85.7)                   | 1 (14.3)                 |                                                                                  |
| Rotenberg et al⁹/2013| PCS   | 11 (14 ears) | Endoscopic closure of ET (cautery, fat placed in ET, ET orifice sutured, tissue glue injected into the torus orifice) and tympanostomy tube | 13 (92.8)                  |                          | Epistaxis: 1                                                                    |
| Ikeda et al⁹/2011  | RCS        | 13 ears      | Transtympanic ET plugging with a Kobayashi PEP through a myringotomy      | 13 ears (100)              |                          |                                                                                  |
| Takano et al⁹/2007 | PCS        | 10 (15 ears) | Endoscopic transnasal/transoral ligation of pharyngeal orifice of ET       | 2 (13.3)                   | 7 (46.7)                  | Temporary OME: 1                                                                |
|                    |            |              |                                                                           |                            |                          | Infection: 1                                                                    |
|                    |            |              |                                                                           |                            |                          | Odynophagia: 1                                                                 |
|                    |            |              |                                                                           |                            |                          | Revision operations: 3                                                           |
| Sato et al⁹/2005   | RCS        | 35 (42 ears) | Transtympanic insertion of silicone plug via a myringotomy                | 22 (52.4)                  | 8 (19)                    | Foreign body sensation                                                          |
|                    |            |              |                                                                           |                            | 11 exchanged for larger plug                                                 |
| Doherty & Slattery⁹/2003 | RCS  | 2            | Complete closure of ET at nasopharyngeal orifice (cautery of the internal circumference of the ET orifice, fat graft, further electrocautery) and tympanostomy tubes | 2 (100)                    |                          |                                                                                  |
| Dyer Jr & McElveen⁸/1991 | Case report | 1            | Transcanal insertion of an angio-catheter into the ET via tympanomeatal flap and tympanostomy tube | 1 (100)                    |                          |                                                                                  |
| Bluestone & Cantekin⁸/1981 | RCS   | 4            | Transtympanic insertion of IV indwelling catheter through a tympanotomy and tympanostomy tube | 4 (100)                    |                          |                                                                                  |

PEP: patulous eustachian tube plug, OME: otitis media with effusion, OM: otitis media, CT: computed tomography, TMP: tympanic membrane perforation, TMJ: tempromandibular joint, CHL: conductive hearing loss, ET: eustachian tube, MEE: middle ear effusion, RCS: retrospective case series, PCS: prospective case series

PEP: patulous eustachian tube plug, OME: otitis media with effusion, OM: otitis media, CT: computed tomography, TMP: tympanic membrane perforation, TMJ: tempromandibular joint, CHL: conductive hearing loss, ET: eustachian tube, MEE: middle ear effusion, RCS: retrospective case series, PCS: prospective case series

Management of patulous eustachian tube ... Khurayzi et al
Table 4 - Outcomes from 10 studies reporting treatment of patulous eustachian tube through eustachian tube occlusion (continuation).

| Author/rear                      | Study type | Subjects (n) | Treatment                                           | Complete resolution n (%) | Partial resolution n (%) | Adverse events                                                                 |
|----------------------------------|------------|--------------|-----------------------------------------------------|---------------------------|--------------------------|--------------------------------------------------------------------------------|
| Robinson & Robinson²/1989        | RCS        | 5 (6 ears)   | Eustachian tube diathermy                            | 4 (66.7)                  | 1 (16.7)                 | Secretory OM: 2                                                                |
| O’Connor & Shea¹/1981            | RCS        | 6            | 20% silver nitrate cautery                          | 5 (83.3)                  | 1 (16.7)                 | Serous OM: 1                                                                   |
|                                   |            |              | CT-guided transcutaneous injection using polydimethylsiloxane elastomer (Vox) | 7 ears (58)               | 4 ears (33.3)            | MEE: 1 ear, Ear pain: 1 ear                                                   |
|                                   |            |              |                                                      |                           |                          | Numbness in the distribution of the maxillary nerve: 4 ears                   |
|                                   |            |              |                                                      |                           |                          | Numbness of face on the side of the treated ear: 3 cases                     |
|                                   |            |              |                                                      |                           |                          | Numbness of the tongue: 1 case                                                |
|                                   |            |              |                                                      |                           |                          | Right-sided tinnitus and mild CHL secondary to MEE                            |
| Alli et al³/2019                 | Case series| 8(12 ear)    | CT-guided transcutaneous injection using polydimethylsiloxane elastomer (Vox) | 7 ears (58)               | 4 ears (33.3)            | Serous OM: 1                                                                   |
|                                   |            |              |                                                      |                           |                          | MEE: 1 ear, Ear pain: 1 ear                                                   |
|                                   |            |              |                                                      |                           |                          | Numbness in the distribution of the maxillary nerve: 4 ears                   |
|                                   |            |              |                                                      |                           |                          | Numbness of face on the side of the treated ear: 3 cases                     |
|                                   |            |              |                                                      |                           |                          | Numbness of the tongue: 1 case                                                |
| Jolly et al⁴/2018                | Case report| 1            | ET obliteration using endovascular coils            | 1 (100)                   |                          |                                                                                  |
| Jančatová et al⁵/2018            | Case report| 1            | CT-guided transcutaneous injection using polydimethylsiloxane elastomer (Vox) | 1 (100)                   |                          |                                                                                  |
| Oh et al⁶/2016                   | RCS        | 25 (33 ears) | Autologous cartilage injection                      | 9 ears (27.3)             | 14 ears (42.4)           | Temporary OME: 1                                                               |
| Mackeith & Bottrill⁷/2016        | RCS        | 11           | Combined transnasal-transoral endoscopic injection of Polydimethylsiloxane elastomer | 8 (73)                    | 1                         | Persistent MEE: 1                                                               |
|                                   |            |              | Endoscopic injection of soft tissue bulking agent into torus tubarius (vox-implants) | 7 (35)                    | 6 (30)                    | Temporary effusions: 2                                                         |
| Schroder et al⁷/2015             | RCS        | 20 (26 ears) | Transnasal endoscopic injection of calcium hydroxyapatite to ET orifice | 1 (100)                   |                          |                                                                                  |
| Oh et al⁸/2014                   | Case report| 1            | Autologous cartilage injection to anterior/posterior nasopharyngeal ET orifice | 1 (100)                   |                          |                                                                                  |
| Vaezaasharet et al⁹/2014         | RCS        | 14 (23 ears) | Transnasal endoscopic injection of calcium hydroxyapatite to ET orifice | (57-63)                   |                          |                                                                                  |
|                                   |            |              | Transcutaneous CT guided silicone elastomer suspension implant | 1 (100)                   |                          |                                                                                  |
| Rodrigues et al¹⁰/2014           | Case report| 1            | Autologous cartilage injection to anterior/posterior nasopharyngeal ET orifice | 1 (100)                   |                          |                                                                                  |
| Kong et al¹¹/2011                | RCS        | 2            | Transoral injection of calcium hydroxyapatite to lateral pharyngeal wall and torus tubarius | 2 (100)                   |                          |                                                                                  |
|                                   |            |              | Endoscopic patulous ET reconstruction: Cartilage graft 2 Pts; AlloDerm 12 Pts: placed around ET orifice | 1 (100)                   |                          |                                                                                  |
| Wrolaich & Zur²²/2010            | Case report| 1            | Polytef paste injection                             | 1 (7)                     | 12 (86)                  | Temporary OME: 1                                                               |
| Poe²³/2007                       | PCS        | 11 (14 ears) | Infusion of absorbable gelatin sponge solution into ET (1 g gelfoam, 10 ml glycerin + 10 ml saline + 1 g carbomethylcellulose sodium) | 1 (7)                     | 12 (86)                  |                                                                                  |
| Crary et al²⁴/1979               | PCS        | 10           | Polytef paste injection                             | 9 (90)                    |                          |                                                                                  |
| Ogawa et al²⁵/1976               | PCS        | 16 (22 ears) | Infusion of absorbable gelatin sponge solution into ET (1 g gelfoam, 10 ml glycerin + 10 ml saline + 1 g carbomethylcellulose sodium) | 22 (100)                  |                          | Temporary tinnitus: 2                                                          |
| Pulec²⁶/1967                     | RCS        | 26           | Teflon to anterior ET                               | 19 (73.1)                 | 6 (23.1)                 | Ear or TMJ discomfort                                                          |

PEP: patulous eustachian tube plug, OME: otitis media with effusion, OM: otitis media, CT: computed tomography, TMP: tympanic membrane perforation, TMJ: tempromandibular joint, CHL: conductive hearing loss, ET: eustachian tube, MEE: middle ear effusion, RCS: retrospective case series.

PCS: prospective case series.
the ET and was investigated as a potential therapeutic approach to PET. Appendix 1 summarizes relevant evidence. The most commonly investigated technique was tensor veli palatine transaction or transposition with pterygoid hamulotomy, which was reported by Virtanen (44) on 16 ears, with a CRR of 56.2%.

**Diagnostic approaches.** Ten studies including 367 subjects investigated various diagnostic methods.55-64 The various diagnostic options summarized in this review (Table 5) include the 678 Hz acoustic immittance probe tone of GSI TympStar Middle Ear Analyzer (Grason-Stadler, Eden Prairie, MN, USA), patient-reported outcome measure (PROM), sonotubometry acoustic click stimulus, nasal-noise masking audiometry (NNMA), computed tomography in the sitting position, and sonotubometry.

**Discussion.** Patulous eustachian tube is a modestly prevalent condition that impacts the quality of life of affected individuals. The recognition of and approach to this condition is usually challenging due to the highly subjective nature of the disease and various management options that fail to be consistent in terms of clinical efficacy.3 The present systematic review summarized therapeutic and diagnostic options published in the literature, updated previous work in this field, and included more studies and approaches compared with previous reviews. Although the diagnosis of PET is mainly clinical, several approaches have been proposed to confirm the diagnosis.3 This is significant because symptoms can be nonspecific or misleading in some instances, especially autophony, which is often incorrectly regarded as a pathognomonic sign of PET; while several other conditions may precipitate it, such as external ear canal occlusion, superior canal dehiscence, and foreign bodies such as hair or wax.165 These approaches are

### Table 5 - Summary of 10 studies reporting different applied diagnostic methods of patulous eustachian tube.

| Author/Year | Study design | Procedure | Sample size | Outcome |
|-------------|--------------|-----------|-------------|---------|
| Pyne et al13/2018 | PCS | The 678 Hz acoustic immittance probe tone of GSI TympStar Middle Ear Analyzer | Healthy:11 (11 ears) PET: 7 (7 ears) | The 678 Hz tone yields a larger response for PET than the 226 Hz tone. For the 226 Hz tone PET patients had a median COT difference 0.19 mL higher than healthy ET patients, and for the 678 Hz tone, PET patients had a median COT difference of 0.57 mL higher than healthy ET patients |
| Smith et al14/2018 | PCS | patient-reported outcome measure (PROM) | Obstructive ET: 33 Hearing loss and Menier’s: 24 | PROM had excellent diagnostic accuracy using only healthy controls as comparator for ETD, but specificity was very poor when controls with other otologic disorders were included. |
| Pyne et al13/2017 | PCS | sonotubometry acoustic click stimulus | Healthy:11 (19 ears) PET: 5 (6 ears) | Novel click stimulus described is a reliable method to determine ET opening in healthy ears, and distinguish between healthy ET and PET states |
| Paradis et al15/2015 | RCS | nasal-noise masking audiometry (NNMA) | Healthy:10 (20 ears) PET: 21 (42 ears) | Definitive and probable PET groups had significantly higher NNMA mean auditory thresholds compared to normal ears at 250 Hz, 1,000 Hz and 6,000 Hz. The patulous ET could clearly be visualized from the tympanic to the pharyngeal orifice. |
| Oonk et al16/2014 | Case report | CT in the sitting position | 1 | The full length of the ET could be visualized in most patients suffering from patulous ET in the sitting position |
| Kikuchi et al17/2009 | PCS | CT in the sitting position | 35 | The OTD* was significantly longer in the patulous ET group than in the control group under both resting and Valsalva conditions |
| Kikuchi et al18/2007 | PCS | CT in the sitting position | Healthy: 20 (30 ears) PET: 67 (111 ears) | This caused elevation of the threshold for the tone presented in the external auditory canal which was significantly greater, particularly in the lower-frequency region, in ears with patulous ET and was decreased to the normal range after obstructive treatment of the PET |
| Hori et al19/2006 | PCS | Audiometry with Nasally Presented Masking Noise | Healthy: 10 (20 ears) PET: 18 (27 ears) | The ET lumen was identified at most of the portion from the pharyngeal orifice to the tympanic orifice in sitting position and recumbent position. At the cartilaginous portion, the air space in the ET lumen was larger in the sitting position than in the recumbent position. It is a useful addition for diagnosing the abnormal patency of the Eustachian tube and for following up the results of its treatment |
| Yoshida et al20/2003 | Case report | CT in the sitting position with the MPR technique | 2 | |
| Virtanen et al21/1978 | PCS | sonotubometry | 25 (31 ears) | |

PET: patulous eustachian tube plug, MPR: multiplanar reconstruction, CT: computed tomography, ET: eustachian tube, NNMA: nasal-noise masking audiometry, COT: compliance over time, OTD: open tubal distance
also important for persistent treatment-resistant cases and for research purposes.66 Thus, having a consistent diagnostic approach is important for clinical studies that investigate various management options, and for synthesizing comparative evidence. Meanwhile, there is still no gold standard for diagnosing PET. The most commonly reported approach is computed tomography in the sitting position with or without the Valsalva maneuver, which is used to detect any anatomical patency and measure open tubal distance.60,61 It remains; however, costly, and not readily available in all healthcare centers. Sonotubometry, tympanometry, and audiometry, along with other approaches, that may or may not need special equipment, were summarized in this review to emphasize the need for a tailored, case-specific approach that combines clinical assessment with diagnostic tests to detect PET. Given the results and nature of the included studies, this appears to be better than standard tests. More research is, nevertheless, needed to inform and develop future guidelines.

In terms of therapeutic approaches, several medical and surgical interventions were suggested, none of which, however, proved to be consistently effective.67 Our review highlights the lack of randomized controlled trials and the need for more interventional studies. Non-surgical interventions mainly include the intratympanic or intranasal administration of different agents. Most recent studies have focused on the role of saline instillation for symptom relief in those with PET.28,32 Intranasal saline was suggested as the initial step in the management plan due to its moderate to high efficacy and clean safety profile.32 However, confounders such as instructing patients to stop snifing were reported, especially in those with PET and habitual snifing, which need to be accounted for in future studies. Similar to previous systematic reviews, we failed to find any evidence supporting the use of nasal estrogen cream to treat PET.67

Patients with no clinical improvement and persistent movement of the tympanic membrane may be candidates for combination therapies or surgical treatment.6 The wide spectrum of surgical interventions mainly targets the tympanic membrane, ET orifice or the surrounding anatomical features, and range from simple to invasive procedures. Again, surgical approaches are limited by the lack of consistency of clinical efficacy, scant descriptions of the details of some procedures, and the primitive evidence that we still have in this area. For example, the outcome of “partial resolution” was not consistently defined among the studies.

Our results highlight several additional challenges that impede a more informed approach to PET. Some of these challenges are specific to the nature of the condition, such as the scarcity of objective outcomes and that symptoms can be self-limited, which is an important confounder in research studies. Other challenges leave room for improvement through further research and interventions. They include small sample sizes, high risk of bias, unmatched confounders, poorly defined follow-up periods, and poorly described intervention(s), in addition to the lack of clinical trials and guidelines for diagnosing and managing PET. The present systematic review was limited by the lack of quantitative meta-analysis and the exclusion of non-English articles due to a lack of native speakers.

In conclusion, the present systematic review is the most recent comprehensive investigation of diagnostic and therapeutic approaches to PET to date. It revealed a highly variable spectrum of choices, with a lack of systematic guidelines and several gaps in current research endeavours. As such, a case-specific, step-wise approach is recommended.

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