CT and MRI in the Preoperative Planning of Balloon Dilation of the Eustachian Tube: Literature Review

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Abstract

Balloon dilatation of the Eustachian tube (BET) is a surgical treatment method for Eustachian tube dysfunction (ETD), which relieves the symptoms in the majority of cases. However, there are potential intraoperative risks associated with BET; the decision-making process with regard to indications for BET is not standardized up to date. The objective of this study was to review the role of computed tomography (CT) and magnetic resonance imaging (MRI) in the preoperative planning of BET. The literature review is based on a database search performed in August 2022.

BET is classified into transtympanic and nasopharyngeal. CT of the temporal bone provides good visualization of the site of obstruction, which allows to choose the adequate approach. Transtympanic approach is associated with risks of internal carotid artery damage due to possible carotid canal anomalies. This risk can be prevented with preoperative CT scan of the temporal bone. In case of nasopharyngeal BET, there is no sufficient data considering risks of possible artery damage, although CT can provide accurate measurements of ET. MRI is useful for differential diagnosis of conditions imitating ETD, such as endolymphatic hydrops and nasopharyngeal carcinoma. Thus, it is feasible to perform CT and MRI before BET to personalize the management of ETD patients.

Keywords

- balloon dilation
- CT
- Eustachian tube
- Eustachian tube dysfunction
- MRI

Introduction

Balloon dilatation of the Eustachian tube (BET) is surgical treatment method for Eustachian tube dysfunction (ETD). The first evidence of BET efficiency in ETD management was reported in 2009.[1] The procedure of BET involves inflating a balloon catheter inside the cartilaginous part of the ET. The mechanism of subsequent clinical improvement is supposedly associated with mechanical effect on the mucosa. The balloon catheter removes cells that were irreversibly damaged by inflammation, which results in enhanced regeneration of normal tissue. A thin fibrous layer is formed, and the symptoms of dysfunction (muffled hearing, pain, ear fullness, tinnitus and dizziness)[2,3] are relieved.

Today, BET is the most widely used surgical procedure for ETD; its clinical efficiency has been evaluated in various studies over the last decade.[4] Several researches have proven safety of balloon catheter exposure to the cartilage portion of ET.[5–14] However, potential intraoperative risks associated with BET have been reported. The risks are primarily

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mediated by the specific morphology of ET and configuration of the anatomical structures in the surrounding area. The bony portion of ET lies in close proximity to the internal carotid artery (ICA), specifically its petrous segment, which is located in the carotid canal.[15] Excessive insertion of the catheter toward the proximal end of ET increases the risk of artery damage, which is significantly higher in case of structural abnormalities. Inadequate catheter insertion can cause fractures of the thin bone canal with fragment displacement toward the ICA, leading to dangerous bleeding.[16] Medical intervention in proximity to the carotid is known to cause possible plaque dislodgement and intimal tears.[16] These risks might necessitate preoperative imaging of ET and the nearby structures for the purpose of planning the intervention. Radiological diagnostic methods—computed tomography (CT) and magnetic resonance imaging (MRI) of the temporal bone—provide for efficient preoperative imaging.

Another issue concerning BET is the lack of standardized indication for the procedure. Until now, no defined criteria are specified for the assessment of possible prognostic benefit of BET in patients with ETD. According to the latest meta-analysis, the effect of the procedure is characterized with both subjective and objective improvement in the majority of cases, evaluated with 7-item Eustachian Tube Dysfunction Questionnaire scores, tympanometry, otoscopy findings, and the ability to perform a Valsalva maneuver.[8] However, the efficiency of the intervention is subtotal, as the symptoms of ETD do not resolve in 100% of patients. Thus, the role of CT and/or MRI in this regard is crucial, as these methods allow to predict the results of BET and ensure effectiveness and safety of the intervention.

The aim of this review is to determine the role of CT and/or MRI in the management of patients with ETD undergoing BET.

Materials and Methods

The search was based on the following keywords: ET, ETD, EBT dilation, CT, and MRI.

The main purpose of this study was to evaluate the necessity of CT and/or MRI in preoperative planning of BET. The literature review was performed on August 30, 2022, as recommended by the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) checklist. The following types of studies were included in the review: case reports, systematic reviews, retrospective studies, and prospective studies evaluating the role of CT and MRI in the preoperative management of BET. The authors independently reviewed all abstracts and excluded those that were not relevant to the topic of this study. Studies were included if they met the following inclusion criteria: (1) published articles written in English or German between 2000 and 2021; (2) published articles with full text, written only for the human species; (3) evaluation only for BET; (4) studies related only to ETD. Exclusion criteria included (1) results of other techniques rather than BET and (2) case reports with fewer than two patients.

The literature review was performed by a comprehensive search of PubMed database. The summary of the results using Medical Subject Heading keywords is shown in ►**Tables 1** to **4**.

Table 1 PubMed search results using keywords

Keyword	Database	Total results after inclusion/ exclusion criteria
Eustachian tube	PubMed	5,173 results
Eustachian tube dysfunction	PubMed	2,218 results
Balloon dilation	PubMed	15,641 results
CT	PubMed	541,560 results
MRI	PubMed	713,709 results

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging.

Results

In total, 11 works on the use of CT in the context of BET were analyzed. Of these, three were experimental, performed on cadavers; eight were clinical studies and included patients with ETD (6 studies), healthy volunteers (1 study), and patients whose pathologies were not characterized (1 study). Three studies on the use of MRI in the context of BET were also analyzed.

The data are summarized in ►**Tables 3** and **4** that include the characteristics of patients (if mentioned; ►**Tables 3**–**4**). However, due to the small number of elected studies, it is not appropriate to perform statistical analysis; thus, these tables

Table 2 PubMed cross-match keywords search results

Cross-match keywords	Database	Total results after inclusion/exclusion criteria	Removed results	Nonrelevant	Selected articles
Eustachian tube and balloon dilation	PubMed	177	160	12	5
Eustachian tube dysfunction and CT	PubMed	78	69	3	6
Eustachian tube dysfunction and MRI	PubMed	66	56	7	3
Total		321	285	22	14

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging.

Table 3 Summary of the literature review of CT in the context of BET

Publication date	2012	2016	2019	2019	2015	2013	2020	2014	2020	2020	2018
Authors	Kepchar et al[17]	Jufas et al[16]	Kapadia et al[19]	Kapadia et al[19]	Tarabichi and Najmi [20]	Tisch et al[21]	Swain et al[22]	Abdel-Aziz et al[23]	Lee et al[24]	El-Anwar et al[25]	Falkenberg-Jensen et al[26]
Cadaver/ clinical study	Cadaver	Cadaver	Cadaver	Clinical	Clinical	Clinical	Clinical	Clinical	Clinical	Clinical	Clinical
Total number of ears/ patients	6 Cadaveric heads, 10 ears	10 Cadaveric heads, 10 ears	8 Cadaveric heads, 15 ears	100 Patients	51 Patients, 53 ears	1,000 Patients, 2,000 ears	21 Patients, 25 ears, 14 male, 7 female, aged over 18	284 patients, 510 ears	29 patients, aged over 18	100 patients, 200 ears, 50 males, 50 females aged from 18 to 76	69 patients, 97 ears, 29 male, 40 female, mean aged 45
Performing of BET	Yes	Yes	Yes	Yes	No[a]	No[a]	Yes	Yes	No[a]	No[a]	Yes
BET approach	Transtympanic	Transtympanic	Transtympanic	Transtympanic	–	–	Nasopharyngeal	Nasopharyngeal	–	–	Nasopharyngeal
Imaging	Postoperative CT	Endoscopic guidance	Endoscopic guidance, CT	Endoscopic guidance, CT	Endoscopic guidance, CT	CT	CT	CT	CT	CT	CT
Parameters assessed	Complications	Complications	Complications	complications	Site of ET obstruction	Carotid canal anomalies	Carotid canal anomalies	Carotid canal anomalies	Site of ET obstruction	The bone and cartilage length, total length of ET, and the width and height of the tympanic orifice of ET	Length of cartilaginous part of ET
Complication after BET	Carotid canal trauma (3)	None	None	None	–	–	None	Soft tissue emphysema (2) hypoglossal paresis (1)	–	–	–
Necessity of preoperative CT	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes

Abbreviations: BET, balloon dilatation of the Eustachian tube; CT, computed tomography.
[a]Studies, in which BET was not performed, although they indirectly relate to the subject of the current review.

Table 4 Summary of the literature review of MRI in the context of BET

Publication date	2020	2012	2021
Authors	Aydın et al[28]	Lükens et al[29]	Bächinger et al[32]
Cadaver/clinical study	Clinical	Clinical	Clinical
Total number of ears	56 ears, aged from 18 to 65	16 patients, 32 ears, 9 male, 7 female, aged from 26 to 82	2 patients, 3 ears, 2 females, aged 42 and age 51
Performing of BET	No	No	Yes
BET approach	–	–	Nasopharyngeal
Imaging	MRI	MRI	Gadolinium-MRI
Parameters accessed	measurement of ET parameters	Reason of ET obstruction	Reason of ET obstruction
Complication after BET	–	–	None
Necessity of preoperative MRI	Yes	Yes	Yes

Abbreviations: BET, balloon dilatation of the Eustachian tube; MRI, magnetic resonance imaging.

only provide a general impression of the issue, as well as the basis for our conclusions.

Discussion

Performing a CT or MRI scan prior to BET is aimed at preventing intraoperative trauma by visualization of ET and surrounding tissues. The most important structure near the bony portion of ET is the ICA, the bony canal of which may have dehiscences. Thus, intraoperative injury to this area will cause profuse bleeding. The risks of such a complication vary for transtympanic and nasopharyngeal BET approaches. Therefore, each method requires a separate discussion.

Role of Temporal Bone CT in Planning Transtympanic BET

Transtympanic approach includes BET as part of surgical intervention on the middle ear. One of the first cadaver studies raised the issue of the safety of this procedure. Transtympanic BET was performed on six cadaver heads (10 ears) under the microscope. No middle ear or skull base pathology was detected before the study. Subsequently, CT of the temporal bones showed that carotid canal trauma occurred in two specimens: one of them was damaged on the right side and the other bilaterally. The damaged specimens had preexisting temporal bone fractures that had not been detected before the intervention. It is noteworthy that during the procedure the catheter misplacement into the carotid canal did not emerge in any way and was recorded only on the postoperative CT scan. These facts reveal significant safety issues of BET performed through tympanic approach and under microscopic control only. Accordingly, there is a likelihood of surgical error associated with lacking data on the surrounding anatomical structures.[17]

Subsequent cadaveric studies have introduced endoscopic guidance as an additional method of control. The course of the catheter was monitored from both protympanic and nasopharyngeal sides of ET, which allowed to completely avoid complications of transtympanic BET. Thus, Jufas et al performed such a procedure in 10 cadaveric heads (10 ears) using dual endoscopic control. No damage to the surrounding anatomical structures was detected. Nevertheless, the authors emphasized the need to ensure complete safety of the ICA. In one of the cases, small dehiscence of the carotid canal was present; in the authors' opinion, this would become a contraindication to surgery in a real patient.[16]

Another cadaveric study also involved transtympanic BET with dual endoscopic control. The authors used CT to detail the course of the ICA regarding ET. Conventional axial CT scan gives the impression that the ICA lies in close proximity to ET in its entire length. CT of the temporal bone with multiplanar reconstruction, on the contrary, allows for a more detailed assessment of the interlocation of these structures, which lie in close proximity only within the small section of the bony part of ET. Therefore, careful endoscopic examination of this area, renders the procedure safe, and preoperative CT unnecessary. BET was performed in 8 cadaveric heads (15 ears) with no damage done to the surrounding structures. The authors stated good endoscopic guidance as the key factor to avoiding complications (in this study 30° rigid endoscope was used).[18]

Thereafter, Kapadia et al also performed transtympanic BET under endoscopic guidance in 100 patients. No bleeding was observed in any case.[19] In addition to endoscopic safety control, the authors emphasize the importance of identifying the site of ET obstruction. As an argument, they cite the results of their own study (2015). Using Valsalva CT and endoscopy, the patency of different sections of ET was studied (CT of the temporal bone was performed simultaneously with the Valsalva maneuver). The authors used data of 51 patients (53 auditory tubes) that underwent middle ear surgery. It was revealed that the most frequent site of ET obstruction in this group was the proximal part of ET close to the protympanum.[20] Authors state that knowledge of the exact location of the ET block defines the choice of either nasopharyngeal or transtympanic approach. It is recommended to combine the intervention with preoperative

Valsalva-CT, endoscopic monitoring, and pre- and intraoperative measurement of auditory tube opening pressure.[19]

However, not all authors agree on the need for preoperative imaging. Tisch et al analyzed 1000 CT images (2000 carotid canals) for carotid canal digestion, aneurysms, or other vascular malformations and found none. The authors consider it unreasonable to expose patients to unnecessary radiation and overuse healthcare resources in search for rare anomalies.[21]

Role of Temporal Bone CT in Planning Nasopharyngeal BET

Nasopharyngeal BET approach is also used in clinical practice. Currently, there are no studies concerning the likelihood of ICA damage from such approach, rendering the risk only hypothetical. There is also no data on whether CT or MRI should be mandatory used prior to the procedure. The argument here may only be based on the subjective opinion of the authors of clinical trials. Swain et al describe the results of a retrospective study of 21 patients with auditory tube dysfunction that underwent nasopharyngeal BET. A CT scan of the temporal bone before and after the procedure was performed for all patients; no abnormalities or lesions were found. The authors believe that the risks of injury to the ICA in case of nasopharyngeal approach are minimal. There is, therefore, no need to include mandatory CT scanning in the routine preoperative examination.[22]

This opinion is shared by Abdel-Aziz et al. The authors conducted a retrospective study of preoperative CT images of 284 patients with ETD (510 auditory tubes). Carotid canal dehiscence was present in 18 patients (6.3%). In three patients (4 auditory tubes), intervention was not completed due to difficulties with balloon catheter insertion. Only one patient of these had bilateral carotid canal dehiscence. Other two CT scans showed no anatomical anomalies. Three cases of postoperative complications were reported after nasopharyngeal balloon dilatation: two cases of soft tissue emphysema and one case of hypoglossal paresis. However, CT scans of these patients did not reveal any abnormalities. Therefore, it was concluded that preoperative CT scanning is not sufficient to predict possible complications of balloon dilatation. The authors state that the key to ensuring success of the intervention for the healthcare specialist is to be increasingly careful as well as to use a device with an integrated dilatation stop mechanism to avoid too deep catheter insertion. The authors, however, believe that a preoperative CT scan can be useful in the practice of inexperienced surgeons to understand the relationship between the auditory tube and the ICA.[23]

Lee et al on the contrary insist on the visualization of the obstruction site before BET. The authors performed Valsalva-CT with measurement of ET parameters in 29 patients with ETD. Their findings indicate that the location of the narrowed area varies and can include the cartilaginous portion, the bony portion, or the isthmus region. BET is currently aimed at eliminating the obstruction in the cartilaginous part of ET and is performed mostly from nasopharyngeal approach. The authors suggest the necessity to determine the site of obstruction for optimal surgery planning. Preoperative Valsalva-CT aids in the adequate choice between nasopharyngeal or transtympanic approach.[24]

El-Anwar et al, who studied CT efficiency in evaluation of various auditory tube measurements, insist on performing a CT scan before nasopharyngeal BET. CT images of 100 healthy volunteers (200 auditory tubes) were studied and several parameters were measured, including the bone and cartilage length, total length of ET, and the width and height of the tympanic orifice of ET. The authors believe that knowing these parameters is necessary for surgeons to choose the optimal catheter size (e.g., the length of the cartilaginous part was found to be shorter in women than in men) as well as for proper balloon placement (the angle between the auditory tube and the Reid plane is smaller in women than in men).[25]

Falkenberg-Jensen et al also studied the length of cartilaginous part of ET before performing BET. Authors used temporal bone CT scans of 69 patients, who had ETD and underwent BET. The results correlate with the aforementioned study, and suggest a greater cartilage length in men. The authors believe that this information is useful in calculation of the depth of catheter insertion.[26]

Role of Temporal Bone MRI in Planning of BET

Several studies have raised the issue of MRI prior to BET. In particular, Aydın et al emphasize the importance of preoperative MRI of cartilaginous portion of ET. The study focused on different cartilage parameters and their features in patients with middle ear pathology (56 ears) in comparison to the control group without middle ear pathology (100 ears). The parameter that correlated with the presence of middle ear pathology was the diameter of the cartilaginous part lumen, measured at the level of isthmus, which is the narrowest part of ET that determines its normal functioning. Reportedly, decreased isthmus diameter is one of the factors known to contribute to otitis media development.[27] For these reasons, the authors considered MRI to be an important part of planning ear surgery, particularly BET. MRI is also a valuable tool for studying and introducing new treatment methods.[28] The advantage of MRI in this case is clearer visualization of the cartilaginous portion of ET, which gives more information about the target area of BET.

Another study illustrates the role of MRI in the differential diagnosis of conditions similar to ETD. This work describes the MRI findings of 16 patients (32 auditory tubes) with clinically confirmed ETD. Five ET blocks were caused by tumor tissue (nasopharyngeal or oropharyngeal carcinoma). In two of the five cases, the tumor had spread to the opposite side (beyond the midline), which caused an obstruction to the opening of both ET.[29]

Another study shows the importance of MRI in the context of differentiation between ETD and endolymphatic hydrops. For example, Meniere's disease associated with increased inner ear pressure (known as endolymphatic hydrops) may present with no clear clinical picture, but isolated symptoms, such as ear fullness, which can mimic ETD.[30,31] This creates the possibility of wrong diagnosis, which is followed by

unnecessary invasive treatment. Such case is demonstrated in the given retrospective study, which reports two cases (women, 42 and 51 years old). The leading complaint was ear fullness: one patient had a unilateral process, with a type "A" tympanogram, and the second patient had a bilateral process with a type "B" tympanogram. Both patients were initially treated for ETD with BET, which proved ineffective. Subsequently, gadolinium-MRI of the inner ear (contrast-enhanced gadolinium MRI) revealed endolymphatic hydrops. The scans of asymptomatic ears showed no pathology. In this case, the misdiagnosis led to excessive invasive treatment. The obtained results raise discussion whether MRI is necessary in preparation for BET.[32]

Limitations

The authors believe that the expected benefits of CT and MRI before BET have been confirmed in this study, although there is a variety of limitations in this literature review. The limitations of the study are related to the small number of cases, which is therefore difficult to evaluate statistically. Some of the discussed studies are based on subjective assessment. Therefore, it is crucial to conduct a randomized, statistically significant study with a larger sample to assess the feasibility of preoperative imaging.

Conclusion

The choice between nasopharyngeal or transtympanic approach for BET depends directly on the site of ET obstruction. CT scan of the temporal bone, especially Valsalva CT, can provide key information. Nasopharyngeal approach is currently indicated for cartilaginous level of obstruction. Transtympanic approach is more adequate if the obstruction site lies in proximity to the bony portion of ET. In our opinion, transtympanic approach is a newer technique that requires further research and is recommended to be performed with simultaneous middle ear surgery. The choice of surgical approach also affects the safety of the technique. In case of transtympanic BET the risk of the ICA damage is conditioned by its proximity to the bony part of ET. Despite the rarity of carotid canal dehiscences and other abnormalities, such findings should be a contraindication for BET and change the tactics of the surgeon. Thus, it is reasonable to perform CT imaging before BET to detect anomalies even if endoscopic control of the procedure is possible.

Both MRI and CT examination are valuable diagnostic tools, especially with regard to cancer alertness. However, MRI is preferable for differentiation between ETD and endolymphatic hydrops. Correct diagnosis is crucial to avoid unnecessary invasive treatment such as BET in patients with pathology unrelated to ETD.

The data provided suggests the feasibility of using CT and MRI as part of the planning of BET. Including these visualization methods in the preoperative examination will aid individualized management of patients with ETD. Despite the lack of information regarding the impact of preoperative CT and MRI on the response to treatment, these methods are certainly useful for selection of BET approach, as well as for differential diagnosis, which increases the effectiveness of treatment.

In general, the success of BET depends on the sufficiency of information about the course of the catheter and the anatomical structure of the ET. Therefore, it is necessary to study not only feasibility of preoperative imaging but also efficiency of intraoperative control of the catheter course (fluoroscopy-guided balloon dilation). Further studies are needed to decide whether fluoroscopic guidance is able to minimize frequency of BET complications.

Conflict of Interest
None declared.

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