European Radiology (2018) 28:3685–3691
https://doi.org/10.1007/s00330-018-5392-4

VASCULAR-INTERVENTIONAL

Fluoroscopic subtraction Eustachian tubography: initial feasibility test in a cadaver model

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Received: 6 December 2017 / Revised: 29 January 2018 / Accepted: 20 February 2018 / Published online: 4 April 2018

Abstract

Objectives To evaluate the technical feasibility of direct Eustachian tube catheterisation and subtraction Eustachian tubography in a cadaver model.

Methods A total of 12 separate sessions were performed on both sides of the Eustachian tube (ET) in six human cadavers. Cadavers were positioned for the submentovertical view on a fluoroscopy table. Endoscopy-guided ET selection was used in the first three cadavers, whereas fluoroscopy-guided ET selection was used in the remaining three. Eustachian tubography was performed by injecting 2 ml of contrast media through a 5-Fr catheter. We recorded the success of ET selection, number of attempts, procedure time, and tubography quality using native and subtraction images (range, 0–3).

Results Both endoscopy- and fluoroscopy-guided selections were successfully performed in five of six sessions (83.3%). There were no statistically significant differences between the endoscopy- and fluoroscopy-guided procedures in terms of the number of attempts, procedure time, rate of immediate contrast leak to the middle ear cavity, and quality of tubography ($p > 0.05$). An excellent quality of tubography was obtained in 83.3% (10 of 12 sessions) of subtraction images and in 33.3% (4 of 12 sessions) of native images. The tubography quality score was significantly higher for the subtraction images than for the native images ($p = 0.04$).

Conclusion Subtraction Eustachian tubography using direct catheterisation seems to be technically feasible. The entire ET can be well visualised; thus, this technique can be used as a simple tool for assessment of ET function and anatomy.

Key Points

• *Direct catheterisation of the Eustachian tube is technically feasible.*
• *The entire Eustachian tube could be well visualised by direct Eustachian tubography.*
• *Subtraction Eustachian tubography images have better image quality than native images.*
• *Subtraction Eustachian tubography can provide objective assessment of ET function and anatomy.*

Keywords Eustachian tube · Radiography, interventional · Otitis media with effusion · Dilatation · Constriction, pathological

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Abbreviations
ET Eustachian tube

Introduction

The Eustachian tube (ET) is a narrow tubular structure extending from the nasopharynx to the middle ear [1]. There are three main functions of the ET: (1) equalisation of middle ear pressure with the surrounding atmospheric pressure, (2) clearance of middle ear secretions by mucociliary movement, and (3) prevention of retrograde passage of speech sounds and secretions from the nasopharynx [2]. Long-term loss of ET function could be a common cause of middle ear morbidities such as chronic otitis media. The conventional treatment for ET dysfunction has been tympanostomy with ventilation tube insertion. It can act as a temporary surrogate ET, but because of its prosthetic nature, is prone to extrusion and infection from external sources.

With recent developments in minimally invasive procedures, balloon dilation of the ET has been used to treat ET dysfunction with promising results [3]. However, objective measurement of the effectiveness of balloon dilation is still challenging [4]. Several tools have been developed to assess ET dysfunction objectively. One study used an externally validated Eustachian tube dysfunction questionnaire score (ETDQ-7) [5], which has been shown to have > 90% sensitivity and specificity in several studies [6–8]. Tubomanometry is a semi-objective method to assess ET function, by providing information about triggering pressure that opens the ET at defined pressures (e.g. 30, 40 and 50 mbar). The combination of tubomanometry and symptom score provides a more objective modality for the assessment of ET dysfunction [9]. However, these methods could not provide anatomical images of the ET. Radiological imaging may be used for assessment of the anatomical and functional status of the ET before and after balloon dilation. Nevertheless, to our knowledge, it has never been applied in conjunction with ET balloon dilation. Most previous researchers used only endoscopy to monitor the procedure, and none of these studies used radiological assessment of the ET. The unavailability of the imaging modalities in the operating room may have been responsible for their limited use.

Kim et al. recently reported that the use of fluoroscopic guidance during ET balloon dilation is useful for monitoring balloon catheter localisation and inflation status [10]. They suggested that the radiological submentovertical view that is necessary for visualisation of the ET could be achieved in the angiography room by applying X-ray tube tilting and extension of the patient's neck. Early experiments in Eustachian tubography were also performed under radiological monitoring [11–14]. Wittenborg et al. [11] reported reflux and subsequent clearing of the contrast media via action of the cartilaginous ET after contrast media filling of the nasopharynx. In their technique, the nasopharyngeal cavity was fully filled with contrast media. It would make it impossible to distinguish between the contrast media and the other instruments used in interventional treatment. We hypothesised that direct catheterisation of the ET would allow it to be imaged with a relatively small amount of contrast media. In addition, it would enable use of the digital subtraction technique, which has been widely used in vascular intervention when performing Eustachian tubography. Thus, the purpose of this study was to evaluate the technical feasibility of direct catheterisation of the ET under fluoroscopic guidance and to determine the quality of Eustachian tubography using the digital subtraction technique.

Materials and Methods

The procedure was performed on both sides of the ET in six fresh-frozen cadavers, yielding a total of 12 separate sessions. All procedures were performed by an interventional radiologist and otolaryngologist with experience in performing ET balloon dilation, which combines endoscopy and fluoroscopy.

Cadaver position

Cadavers were positioned for the submentovertical view because it was found to afford the optimal projection for the visualisation of the nasopharynx-ET-middle ear-mastoid complex [12]. In the classical position for the submentovertical view, the head is extended 90° so that the incident beam is perpendicular to and the detector is parallel to the radiographic baseline of the skull. We developed a modified setting for the submentovertical view to reduce excessive neck extension, which could cause discomfort during the procedure (Fig. 1) [10]. In our modified setting, a specially designed holder was used to elevate the shoulders and trunk and to place the head and neck at approximately 60° extension. In addition, the X-ray tube was caudally tilted 30° according to the patient's neck extension status to achieve the submentovertical view. The horizontal centre of the beam was at a point midway between the angles of the mandible.

After positioning, the nasal cavities of the specimens were cleaned using endoscopy and a suction device. A hostile nasal cavity status that could affect procedure performance, such as a deviated nasal septum or narrowed inferior turbinate due to mucosal hypertrophy, was evaluated.

Endoscopy-guided catheterisation

Endoscopy-guided ET selection was applied to the first three cadavers. A flexible fibre endoscope (ENF-VH Video Rhinolaryngoscope; Olympus, Tokyo, Japan) was used to

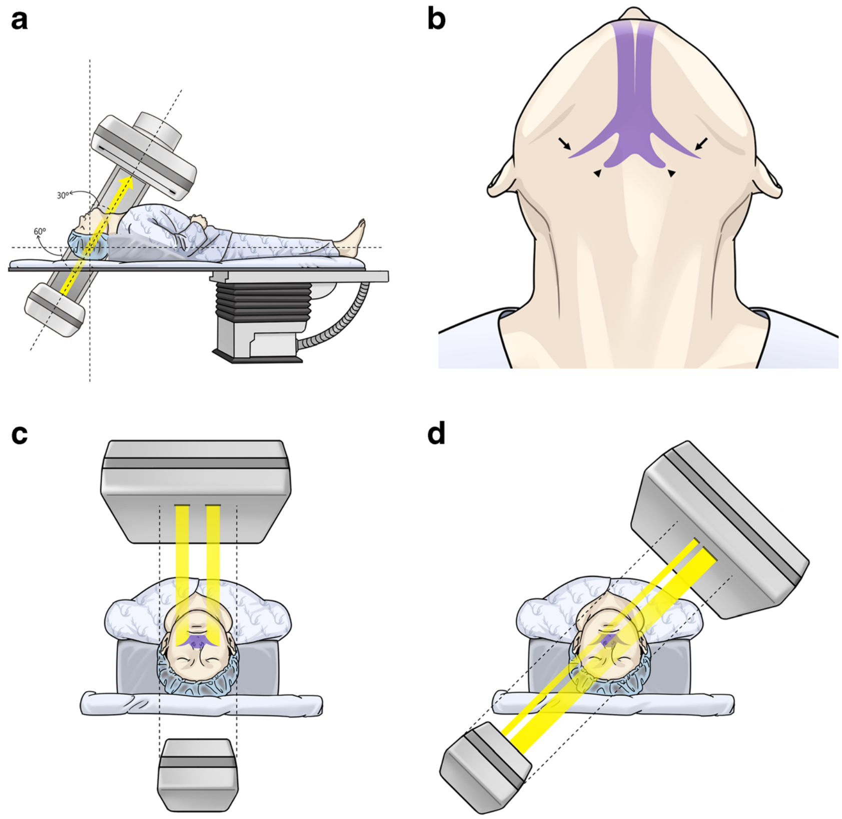

Fig. 1. Modified hirtz position for the submentovertical view. (**a**) Each patient was placed on the fluoroscopy table in the supine position with the shoulders and trunk elevated and with the head and neck at approximately 60° extension. The X-ray tube was caudally tilted 30° according to the patient's extension status. (**b**) View from the submental side. Both sides of the Eustachian tube (arrows) and the fossa of Rosenmüller (arrowheads) are visualised. (**c**) Projection of the Eustachian tube in the posteroanterior view. (**d**) Projection of the Eustachian tube in the oblique view, which enables visualisation of the entire length of a unilateral Eustachian tube

visualise the ET orifice. A short-tip sheath with a 65° tip of 8-mm length (Fig. 2) was introduced transnasally and positioned at the orifice of the ET under endoscopic guidance. It was then rotated so that the sheath tip was flush with the ET orifice and angled parallel to the long axis of the ET. A 5-Fr angiographic catheter (Kumpe catheter; Cook, Bloomington, IN) was

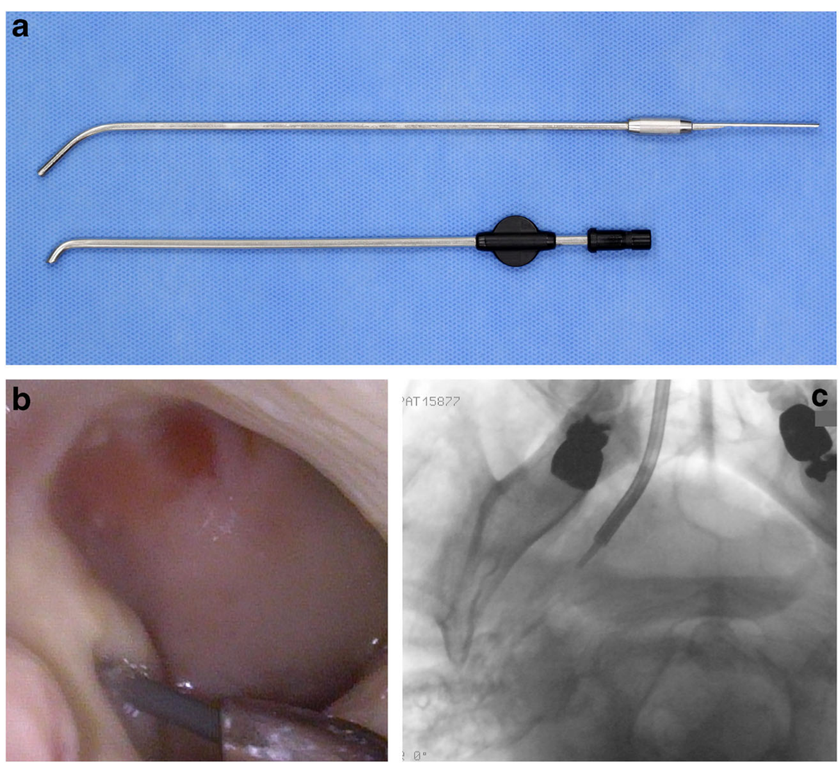

Fig. 2. Photograph of the two sheaths used in Eustachian tubography. (**a**) A long-tip sheath with a 20-mm-long 30° tip (top) was used for fluoroscopic purposes, whereas a short-tip sheath with an 8-mm-long 65° tip (below) was used for endoscopic purposes. (**b**) Image from endoscopy-guided Eustachian tube selection. (**c**) Image from fluoroscopy-guided Eustachian tube selection

combined with a 0.035-inch guide wire (Radiofocus M; Terumo, Tokyo, Japan) was inserted through the sheath until the tip of the catheter was positioned at the ET orifice. Then, the guide wire was manipulated to negotiate it into the ET and middle ear cavity under fluoroscopic guidance. After it was confirmed that the guide wire had successfully passed through the bony canal of the ET without kinking, the Kumpe catheter was advanced into the middle of the cartilaginous part of the ET along the guide wire. If endoscopy-guided catheterisation failed, fluoroscopy-guided catheterisation was performed.

Fluoroscopy-guided catheterisation

Fluoroscopy-guided ET selection was applied to the remaining three cadavers. Under fluoroscopic guidance, a long-tip sheath with a 30° tip of 20-mm length was introduced transnasally with its tip facing downward until it reached the posterior wall of the nasopharynx. Then, the sheath was rotated laterally and slightly pulled back so that its tip reached the fossa of Rosenmüller. The sheath was pulled back approximately 1 cm to pass the torus tubarius. Afterward, the sheath was rotated superolaterally to locate its tip at the orifice of the ET. Catheterisation was performed using the Kumpe catheter and the guide wire as described above. If fluoroscopy-guided catheterisation failed, endoscopy-guided catheterisation was performed.

Eustachian tubography using the digital subtraction technique

A mobile C-arm X-ray machine (Prostar; DK Medical Systems, Seoul, Korea) was used in this study. Tubography was performed by injecting 2 ml of iodinated contrast media into the ET (Omnipaque 300; GE Healthcare, Cork, Ireland). We tested contrast media at 1:2 and 1:1 dilutions while obtaining native images in the submentovertical view (data not shown), but these concentrations of the contrast media were insufficient to obtain appropriate images. Therefore, non-diluted contrast media was used for Eustachian tubography. Digital subtraction images were obtained in the submentovertical view. Subsequently, native images were obtained in the submentovertical view and the 45° oblique submentovertical view.

Data collection and statistics

To evaluate the technical feasibility of the endoscopic and fluoroscopic catheterisation, we recorded the success of ET selection, number of attempts, and procedure time. To evaluate tubography quality, we used a three-point scale: 3 = excellent, with the entire cartilaginous portion and cartilaginous-bony junction clearly visualised, 2 = good, with the entire cartilaginous portion clearly visualised, but the cartilaginous-bony junction barely visualised, 1 = poor, with the entire cartilaginous portion and/or cartilaginous-bony junction not visualised. Quality was assessed in both the subtraction and native images in the submentovertical view. Immediate contrast leakage to the middle ear cavity was recorded. Imaging analysis was performed by two radiologists in consensus.

Descriptive statistics, including the mean and standard deviation, were calculated for the number of attempts, procedure time, and tubography quality. Fisher's exact test was used to compare the success rate of ET selection between fluoroscopy-guided and endoscopy-guided selection of the ET. The Mann-Whitney U test was used to compare the number of attempts and the procedure time between fluoroscopy- and endoscopy-guided selection of the ET and to compare the quality score between the subtraction image and the native image.

Results

Endoscopy-guided catheterisation

All procedural data are summarised in Table 1. Endoscopy-guided catheterisation was successfully performed in five of six sessions (83.3%). In the right-sided ET of cadaver number 3, endoscopy-guided selection of the ET orifice failed after three attempts because the ET orifice was obscured by severe nasal mucosal hyperplasia. Alternatively, fluoroscopy-guided selection was successfully performed in this session.

Fluoroscopy-guided catheterisation

Fluoroscopy-guided catheterisation was successfully performed in five of six sessions (83.3%). In the left-sided ET of cadaver number 5, fluoroscopy-guided selection of the ET orifice failed after three attempts because the sheath could not be rotated laterally because of nasal septal deviation. Alternatively, endoscopy-guided selection was performed successfully in this session. There were no statistically significant differences between the endoscopy- and fluoroscopy-guided procedures in terms of the number of attempts, procedure time, rate of immediate contrast leak to the middle ear cavity, and quality of tubography ($p > 0.05$).

Eustachian tubography results

An excellent quality of tubography was obtained in 83.3% (10 of 12 sessions) in the subtraction image and 33.3% (4 of 12 sessions) in the native image. The tubography quality score was significantly higher for subtraction images compared with the native images ($p = 0.04$) (Fig. 3). In the right-sided ET of cadaver number 2, the entire amount of injected contrast media flowed into the middle ear cavity because of a deep

Table 1. Results of Eustachian tubography

Specimen	Nasal cavity status	ET selection method	ET cannulation success	Number of attempts	Procedure time, s	Immediate contrast leak to middle ear cavity	Quality of tubography* using digital subtraction	Quality of tubography using native image
1R	Normal	Endoscopy	Yes	1	70	No	3	2
1L	Normal	Endoscopy	Yes	2	110	No	3	2
2R	Normal	Endoscopy	Yes	1	50	Yes	1	1
2L	Normal	Endoscopy	Yes	1	60	No	3	2
3R, first trial	Mucosal hypertrophy	Endoscopy	No	3	180	N/A	N/A	N/A
3R, second trial	S/A	Fluoroscopy	Yes	1	55	Yes	3	3
3L	S/A	Endoscopy	Yes	2	105	Yes	3	3
4R	Mucosal hypertrophy	Fluoroscopy	Yes	1	80	Yes	3	2
4L	S/A	Fluoroscopy	Yes	1	70	Yes	2	1
5R	Nasal septal deviation	Fluoroscopy	Yes	2	130	Yes	3	3
5L, first trial	S/A	Fluoroscopy	No	3	200	N/A	N/A	N/A
5L, second trial	S/A	Endoscopy	Yes	1	60	No	3	3
6R	Normal	Fluoroscopy	Yes	1	70	Yes	3	2
6L	Normal	Fluoroscopy	Yes	1	85	Yes	3	2

ET Eustachian tube, *N/A* not applicable, *S/A* same as above, *DSA* digital subtraction angiography

* Tubography quality scale: 3, cartilaginous portion and bony portion were clearly demarcated; 2, cartilaginous portion and bony portion were barely demarcated; 1, cartilaginous portion and bony portion could not be demarcated

location of the catheter tip, which yielded poor quality tubography in both the subtraction and native images. Immediate contrast leakage to the middle ear cavity was noted in 66.7% (8 of 12 sessions).

Discussion

Because there have been outstanding developments in ET interventions, we believe that it is necessary to develop a novel imaging technique that can be used in these procedures. Our present study has revealed that direct catheterisation of the ET is technically possible and relatively easy under endoscopic and fluoroscopic guidance. The overall success rates of endoscopic- and fluoroscopic-guided catheterisations were both 83.3%, reaching 100% if the secondary approach after primary failure was included. Additionally, we found that appropriate Eustachian tubography could be achieved with only a small amount of contrast media. Finally, the digital subtraction technique was useful to visualise the ET from the cartilaginous portion to the bony portion.

Endoscopy-guided ET catheterisation and fluoroscopy-guided ET catheterisation were both found to be technically feasible in our current study. Although ET catheterisation under endoscopic guidance is intuitive and could be safely performed in most situations, fluoroscopy guidance was indicated in certain situations. Two cadavers in our present analysis showed severe nasal mucosal hyperplasia that obscured the ET orifice from the endoscopic field of view. One failure occurred for this reason; thus, fluoroscopy-guided catheterisation was performed. Our fluoroscopy-guided ET catheterisation was an application of the ET bougie method. By using this technique, we showed that ET catheterisation could be easily obtained despite severe nasal mucosal hyperplasia. One concern with this technique is nasal mucosal damage due to scratching by the sheath tip. Appropriate caution and endoscopic assistance can minimise the possibility of mucosal injury.

There are two main advantages of direct catheterisation in ET tubography. First, we greatly reduced the total amount of contrast media needed in ET tubography. In the early days of ET tubography, the entire nasopharynx became filled with contrast media. This technique could not be applied in the ET intervention because the instruments used in the intervention would not be distinguishable. Furthermore, over 15 ml of contrast media was needed, which would lead to multiple swallowing events over several minutes and might cause contrast media aspiration. Second, we obtained digital subtraction images via direct injection of contrast media into the ET. Our results indicate that the digital subtraction images have better quality scores than the native images because they offer higher sensitivity for thin structures compared with native images. The inferior quality of the native images is probably due to the high density of the surrounding bone. In the

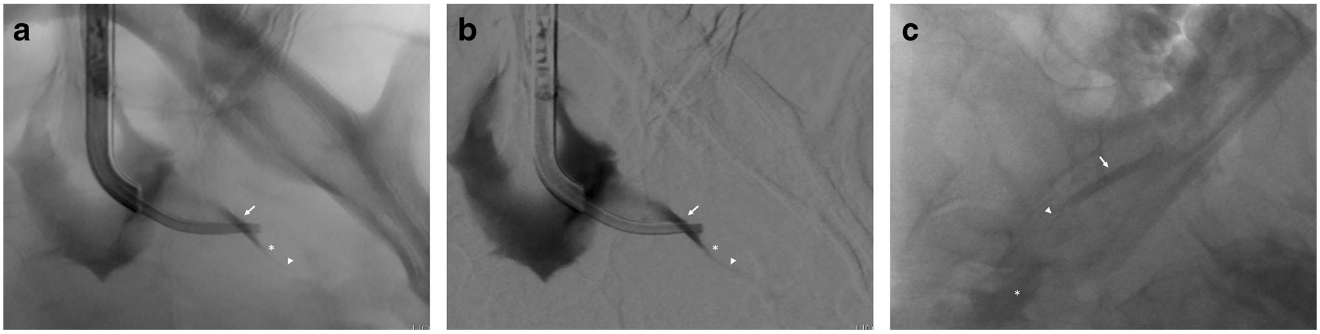

Fig. 3. Eustachian tubography obtained under the submentovertical view. (**a**) Native Eustachian tubography. The cartilaginous portion (arrow) is well depicted, but the cartilaginous-bony junction (asterisk) and bony portion (arrowhead) of the Eustachian tube are blushed. (**b**) Subtraction Eustachian tubography. The cartilaginous portion (arrow), cartilaginous-bony junction (asterisk), and bony portion (arrowhead) are well depicted. (**c**) Native Eustachian tubography in the oblique view. The cartilaginous portion (arrow) and bony portion (arrowhead) are depicted. Contrast media reflux is noted in the middle ear cavity (asterisk) of the Eustachian tube, shown in the oblique view

submentovertical view, the X-ray beam penetrates the skull longitudinally. Therefore, the summation of bone and soft tissue density led to a very high contrast media signal threshold. Despite the use of non-diluted contrast media, the depiction of thin structures such as bony portions was not sufficient in the native images. By using digital subtraction, the entire ET from the cartilaginous portion to the bony portion could be visualised with improved sensitivity for small structures. In addition, this high contrast sensitivity of the digital subtraction technique might further reduce the contrast media amount by decreasing the concentration.

This study had several limitations of note. First, we were unable to relate our findings to ET dysfunction. Further human studies are thus warranted to prove the usefulness of our technique in the diagnosis of ET dysfunction. Second, the total number of specimens was relatively small. There may be a number of potential barriers that affect technical feasibility, such as nasal mucosal hyperplasia, a deviated nasal septum, exudate in the nasal cavity, adenoid hypertrophy, and inferior turbinate narrowing. However, we only validated our technique in cadavers with nasal mucosal hyperplasia and a deviated nasal septum. Third, we did not test native images and digital subtraction images with various concentrations of contrast media. Further studies may be needed to validate the relationship between image quality and optimal contrast concentration.

In conclusion, subtraction Eustachian tubography using direct catheterisation seems to be a technically feasible and informative technique. Direct catheterisation can be obtained with endoscopy or fluoroscopy guidance, and the entire ET can be well depicted by the digital subtraction technique. This approach could therefore be used as a simple ET function and anatomy assessment tool, especially in combination with ET interventions. Further studies are required to establish the role of subtraction Eustachian tubography in the diagnosis and treatment of ET dysfunction.

Funding This study has received funding by Korea Health Technology R&D Project, Ministry for Health, Welfare and Family Affairs, Republic of Korea (HI17C0881).

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Ho-Young Song.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was not required for this study because this study is cadaveric experimental study.

Ethical approval Institutional Review Board approval was not required because this study is a cadaveric experimental study.

Methodology
• Experimental study
• Performed at one institution

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