



Surgery for necrotizing otitis externa—indications and surgical findings

Chilaf Peled¹ · Angelica Parra¹ · Sabri El-saied¹ · Mordechai Kraus¹ · Daniel M. Kaplan¹

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Abstract

Purpose Treatment for necrotizing otitis externa (NOE) includes long term antibiotic and surgery in selected cases. Indications and extent of surgery, however, are still not defined. The aims of this study were: (1) present our experience in surgery for NOE (2) compare high-resolution computer tomography and perioperative findings (3) suggest recommendations for indications and extent of surgery.

Methods A retrospective case series study was conducted in a tertiary referral center. Patients hospitalized due to NOE between the years 1990–2015 and underwent surgery were included.

Results Twenty patients were included in the study. HRTBCT was performed in 17 patients. Most common radiological findings included mastoid fullness ($n = 13$, 76.4%) and edema of external ear canal ($n = 12$, 70.5%). Surgical indications included lack of response to treatment ($n = 18$) and facial nerve palsy ($n = 2$). Seven patients underwent local debridement. Most common operative findings included soft tissue necrosis ($n = 4$, 57.1%) and gross bony destruction of the external ear canal ($n = 2$, 28.5%). Thirteen patients underwent tympanomastoid surgery. Most common operative findings included granulation tissue in the mastoid ($n = 7$, 53.8%) and mastoid bony erosion ($n = 4$, 30.7%). Facial canal involvement was seen in four patients (30.7%).

Conclusion This is the first study to describe a large group of surgically treated NOE. Initial surgical approach should be based on clinical and HRTBCT findings. Minimal HRTBCT findings may be addressed with local debridement. Severe HRTBCT findings should be addressed with canal wall up mastoidectomy as the minimal surgical procedure. Further extent should be decided based on perioperative findings.

Keywords Otitis externa · Necrosis · Surgery · Diabetes mellitus · Malignant

Introduction

Necrotizing otitis externa (NOE) is a severe invasive inflammatory disease affecting mostly elderly diabetic patients. *Pseudomonas Aeruginosa* (PA) is the most common pathogen, however, other bacteria and fungi are also known to cause NOE. Prior to the introduction of anti-PA antibiotics mortality was as high as 67% and surgery was considered the main treatment modality [1]. With the introduction of anti-PA antibiotics, the need for radical surgery has resided

and long-term antibiotic regimen is now recommended as the first-line treatment.

Despite multiple publications on NOE in the last few decades, the role, as well as the indications, timing and extent of surgery are unclear. Several case series reported on the type of surgery performed, and this ranged from local debridement to radical and extended mastoidectomy [2–5]. Operative findings describing anatomical involvement and extent of disease, however, have not been reported.

In a recent publication, our group described 83 NOE patients, among them 20 patients underwent surgery [6]. Operated patients were characterized with a more advanced age, longer duration of hospital stay and a higher rate of readmission. In this study, we focused on those NOE patients who required surgical intervention, to describe the surgical findings and to better evaluate the role of surgery in the treatment of NOE.

✉ Chilaf Peled
chilafp@gmail.com

¹ Department of Otolaryngology-Head and Neck Surgery, Soroka University Medical Center, Faculty of Health Sciences, Ben-Gurion University of the Negev, Yitzhak I. Rager Blvd 151, 84101 Beer-Sheva, Israel

The aims of this study were: (1) present our experience in surgery for NOE, as far as the exact indications, types of procedures performed and findings at surgery (2) compare between high-resolution temporal bone computer tomography (HRTBCT) findings and perioperative findings (3) Define the indications and extent of surgery required.

Methods

All patients admitted to our tertiary care center due to NOE between the years 1990–2015 were evaluated. Diagnosis of NOE was performed based on the Cohen and Friedman criteria [7]. Patients that underwent surgery were defined as the study population. Data included: (1) patient's age and gender, (2) affected ear, (3) medical history, (4) complaints at admission, (5) clinical presentation at admission, (6) culture results, (7) imaging modality (8) antibiotic treatment (9) surgical chart (10) duration of hospitalization.

Surgery was defined as any procedure performed in the operating room under general anesthesia. Local toilette and removal of granulations, in the office were not regarded as surgery.

To compare between preoperative HRTBCT findings and perioperative status we further defined radiological findings of middle ear bone erosion (mastoid, tegmen and ossicular chain) into two main groups: (1) middle ear bone erosion in one subsite (2) middle ear bone erosion in ≥ 2 subsites.

The research was performed in compliance and approval of the medical center's institutional review board; the Human Subjects Research Committee.

Due to the small group size, data is described as frequencies with no further statistical analysis.

Treatment protocol

At admission, all patients were treated empirically, using a single anti-PA antibiotic. Further treatment was based on cultures isolated from local swabs. Patients underwent daily aural toilette and evaluation by an otolaryngologist.

Surgery was performed in the following indications: (1) no response to conservative treatment as assessed by a senior otologist. This was based on continued pain, tenderness of the external ear and lack of local improvement (2) facial palsy. Following surgery patients continued long term antimicrobial therapy.

Results

Twenty patients underwent surgery and were included in the study. Average age at admission was 73.7 years. Otalgia ($n = 17$, 85.0%) and aural discharge ($n = 12$, 60.0%) constituted the most common complaints. The most common

physical findings were external ear canal edema ($n = 13$, 65%) and the presence of granulation tissue ($n = 12$, 60%). Two patients presented with facial nerve palsy (10.0%). Patients characteristics are listed in Table 1.

Microbiology Ear canal swabs, taken prior to surgery, were retrieved in 19 patients. PA was the most common pathogen ($n = 11$, 55%) followed by fungal species ($n = 4$, 20.0%) and sterile cultures ($n = 4$, 20.0%). Deep tissue sterile cultures were retrieved from five patients. In two patients culture results remained similar to initial swab result (PA in both patients). Two patients with swab cultures positive for candida species had a sterile deep tissue culture. One patient with local swab for otomycosis had a positive deep culture for Staph coagulase.

Table 1 Patients' characteristics

Patients	N=20
Age (years)	73.7
Affected ear (Rt.)	13/20 (65%)
Sex (female)	9/20 (45/0%)
Complaints at admission	
Otalgia	17 (85.80%)
Aural discharge	12 (60.0%)
Facial nerve palsy	2 (10.0%)
Physical findings	
External ear canal edema	13 (65.0%)
Discharge	9 (45.0%)
Granulation tissue	12 (60.0%)
Facial palsy	2 (10.0%)
Culture	
Sterile	4 (20.0%)
<i>Pseudomonas aeruginosa</i>	11 (55.0%)
Fungal species	4 (20.0%)
Computer tomography (performed/total)	
Mastoid fullness	13 (65.0%)
External ear canal edema	12 (60.0%)
Middle ear fullness	10 (50.0%)
Mastoid erosion	7 (35.0%)
Tegmen erosion	7 (35.0%)
Skull base erosion	2 (10.0%)
TMJ involvement	1 (5.0%)
Positive Gallium-67 scan (performed/total)	7/20 (35.0%)
Time from admission to surgery (avg. days)	16.4
Surgery type	
Local debridement	7 (35.0%)
CWU mastoidectomy	4 (20%)
CWD mastoidectomy	7 (35.0%)
CWD mastoidectomy with FND	2 (10.0%)
Duration of hospitalization (avg days)	30.3

TMJ temporomandibular joint, CWU canal wall up, CWD canal wall down, FND facial nerve decompression

Surgical findings Eighteen patients (90%) underwent surgery due to lack of response to conservative treatment, while only two patients underwent surgery due to facial nerve palsy (10%). Average timing from admission to surgery was 16.4 days. Surgical charts were retrieved in 17 patients. All three patients in whom surgical charts were not retrieved underwent local debridement as the main surgical procedure.

Seven patients (35.0%) underwent deep local debridement, via the external auditory canal. Surgical findings within this group included external ear canal soft tissue necrosis ($n=4$, 57.1%), external ear canal abscesses ($n=2$, 28.5%), gross bony destruction of the external ear canal ($n=2$, 28.5%) and temporomandibular joint involvement ($n=2$, 28.5%).

Thirteen patients underwent tympanomastoid surgery (65.0%). Surgical procedures included canal wall down mastoidectomy ($n=7$, 35%), canal wall up mastoidectomy ($n=4$, 20%) and canal wall down mastoidectomy with facial nerve decompression ($n=2$, 10%). Operative findings included granulation tissue in the mastoid ($n=7$, 53.8%) tympanic membrane perforation ($n=4$, 30.7%), ossicular chain erosion ($n=3$, 23.0%) and mastoid bony erosion ($n=4$, 30.7%). Facial canal involvement was seen in four patients (30.7%), located at the mastoid segment ($n=3$) and the second genu ($n=1$). Table 2 depicts the patients' radiological, surgical and bacterial findings.

HRTBCT findings Seventeen patients (85.0%) underwent a HRTBCT. The most common radiological findings included mastoid fullness ($n=13$, 76.4%), edema of external ear canal ($n=12$, 70.5%) and middle ear fullness ($n=10$, 58.5%). Most common bony erosion seen on HRTBCT were mastoid and tegmen erosions ($n=7$, 41.1% in both). Two patients exhibited skull base erosion (11.7%) and one patient exhibited temporomandibular joint involvement (5.8%). Seven patients underwent Gallium-67 scan, all with positive results.

HRTBCT and surgery Among the seven patients that underwent local debridement, three patients showed radiological evidence of bone erosion involving one subsite within the middle ear. Among the 13 patients who underwent tympanomastoid surgery, 4 patients exhibited radiological signs of one subsite middle ear bone erosion. Within this subgroup only two patients (50%) showed perioperative findings indicating gross middle ear involvement. Four patients had middle ear bone erosion in two or more subsites on HRTBCT. Among them, three patients (75%) had gross findings of middle ear involvement.

Follow-up Data were retrieved from 11 of patients. Average follow up period was 25.9 months (range 1–91 months). Three patients died shortly after discharged (4 months), all from non-related causes (massive aspiration, respiratory failure, renal failure).

Discussion

The role of surgery in the treatment algorithm of NOE has changed substantially since the introduction of anti-pseudomonas antibiotics. Table 3 depicts the incidence of surgical interventions in selected case series reported over the last four decades. To the best of our knowledge, the presented study is one of the largest and most detailed surgical case series on patients operated due to NOE.

As mentioned earlier, the presented group was previously included in a larger case series published by our group, which evaluated the relationship between clinical findings and course of disease in NOE [6]. In this study, we specifically evaluated surgically treated NOE patients to better understand the role of surgery in NOE and the correlation between perioperative findings and HRTBCT.

We recognize two main limitations to our study: (1) As this was a retrospective study some of the data is incomplete (2) Since all of our patients had substantial clinical improvement and were discharged home, we assume that the surgical intervention was required. It is possible, however, that some patients underwent an extensive procedure which could have been minimized.

Indications for surgery in NOE

Although surgery is probably required for selected cases for the treatment of NOE, there are no clear indications as to when surgery should be performed and to what extent.

Non-responsiveness The most common indication for surgery is non-responsiveness to prolonged antimicrobial treatment. The term “non-responsive” is rather perplexing and may refer to improper antimicrobial dosage, duration, bacterial resistance formation, or lack of proper antibiotic coverage to the causative pathogens (such as fungi), that were not isolated from local swab cultures. In our study, 90% of the patients were operated due to lack of response to treatment, and all were treated similarly to other non-surgical NOE patients. It is possible that bacterial resistance or other pathogens not isolated from swab cultures were the main reasons for treatment failure. Alternatively, it is also possible that systemic effects such as micro-angiopathies secondary to prolonged diabetes prevented sufficient antibiotic delivery to the infected tissue [8]. The decision as to when a patient is considered non-responsive to conservative management is naturally subjective and previous case series have reported treating patients conservatively for 3–4 weeks before considering surgery [9, 10]. In our series, surgery was considered if improvement was not seen after 2 weeks of antibiotic treatment. Clinical improvement was assessed by the treating senior otologist,

Table 2 patients' radiological, surgical and bacterial findings

Pts. No.	Surgery	HRTBCT findings	Gallium-67 scan	Surgical findings	Pre-surgery culture	Deep tissue sterile culture
1	LD	ND	NP	ND	PA	ND
2	LD	ND	NP	EEC abscess drainage EEC necrotic ST	PA	ND
3	LD	EEC edema ME fullness Peri-auricular ST swelling Mastoid erosion	NP	EEC necrotic ST Gross bony destruction of EEC TMJ gross involvement	PA	ND
4	LD	ME fullness Mastoid fullness Tegmen erosion	Positive	EEC abscess drainage EEC necrotic ST Gross bony destruction of EEC TMJ gross involvement	PA	ND
5	LD	EEC edema ME fullness Mastoid fullness Periauricular ST swelling Mastoid erosion	NP	Periauricular necrotic ST EEC necrotic ST	PA	ND
6	LD	ME fullness Mastoid fullness	NP	ND	PA	ND
7	LD	EEC edema	NP	ND	PA	ND
8	CWUM	EEC edema Mastoid fullness Mastoid erosion Tegmen erosion	Positive	Granulation tissue in mastoid Gross mastoid bone erosion	Sterile	ND
9	CWUM	EEC edema ME fullness Mastoid fullness Mastoid erosion Ossicular erosion Tegmen erosion	NP	TM perforation/granulation Ossicular chain destruction Granulation tissue in mastoid Gross mastoid bone erosion	Sterile	ND
10	CWUM	Mastoid fullness Parotid swelling Infratemporal swelling Mastoid erosion	NP	EEC necrotic ST	Candida species	ND
11	CWUM	ND	Positive	EEC necrotic ST	Sterile	ND
12	CWDM	EEC edema Mastoid erosion Tegmen erosion	Positive	EEC abscess drainage EEC necrotic ST Granulation tissue in mastoid	Candida species	Sterile
13	CWDM	EEC edema Mastoid fullness Nasopharyngeal	NP	ND	Sterile	ND

Table 2 (continued)

Pts. No.	Surgery	HRTBCT findings	Gallium-67 scan	Surgical findings	Pre-surgery culture	Deep tissue sterile culture
14	CWDM	ST swelling SB erosion EEC edema ME fullness Mastoid fullness	NP	EEC necrotic ST TM perforation Granulation tissue in ME Granulation tissue in mastoid	PA	PA
15	CWDM	EEC edema ME Fullness Mastoid fullness	Positive	EEC necrotic ST Granulation tissue in ME Gross mastoid bone erosion	Candida species	Sterile
16	CWDM	Tegmen erosion EEC edema ME fullness Mastoid fullness	Positive	Granulation tissue in mastoid Gross mastoid bone erosion Gross FC erosion (mastoid part)	ND	ND
17	CWDM	Tegmen erosion EEC edema Infratemporal ST swelling Mastoid erosion TMJ erosion	NP	EEC necrotic ST TM perforation/granulation Granulation tissue in ME Ossicular chain dist TMJ gross involvement Gross FC erosion (mastoid part)	PA	ND
18	CWDM	ME fullness Mastoid fullness Tegmen erosion	NP	EEC necrotic ST TM perforation/granulation Granulation tissue in ME Ossicular chain discontinuity Granulation tissue in mastoid	Mucor species	Staph. Coagulase negative
19	CWDM + FND	Mastoid fullness	Positive	Granulation tissue in mastoid Gross FC erosion (mastoid part)	PA	ND
20	CWDM + FND	EEC edema ME fullness Mastoid fullness SB erosion	NP	EEC necrotic ST Gross FC erosion (second genu)	PA	PA

HRTBCT high-resolution temporal bone computer tomography, *LD* local debridement, *CWUM* canal wall up mastoidectomy, *CWDM* canal wall down mastoidectomy, *FND* facial nerve decompression, *ME* middle ear, *EEC* external ear canal, *ST* soft tissue, *TMJ* temporomandibular joint, *SB* skull base, *TM* tympanic membrane, *FC* facial canal, *ND* no data, *PA* *Pseudomonas aeruginosa*, *NP* not performed

Table 3 Selected surgical case series reported in the literature

Author	Surgery/total (%)	Surgical intervention
Salit et al. [15]	12/12 (100.0%)	Local debridement ($n = 12$) Mastoidectomy not specified ($n = 4$)
Sade et al. [16]	21/23 (91.3%)	Local debridement ($n = 21$)
Lang et al. [17]	21/23 (91.3%)	ND
Pederson et al. [18]	20/22 (90.9%)	Debridement of granulation tissue, cartilage and sequestra ($n = 20$)
Berenholz et al. [19]	9/28 (32.1%)	ND
Soudry et al. [9] ^a	13/48 (27.0%)	Local debridement ($n = 13$) Canal wall down mastoidectomy ($n = 5$)
Peleg et al. [10]	5/18 (27.7%)	Radical mastoidectomy ($n = ND$) Temporomandibular joint excision ($n = ND$) Parotidectomy ($n = ND$) Partial removal of the zygomatic arch ($n = ND$) Soft tissue debridement of the infratemporal fossa and skull base ($n = ND$)
Lee et al. [20]	7/38 (18.4%)	Mastoidectomy not specified ($n = 7$) Facial nerve decompression ($n = 2$)
Loh et al. [11]	3/19	Local debridement ($n = 3$)
Stern Shavit et al. [4] ^a	20/88 (22.7%)	External ear canal debridement ($n = 12$) Canal wall up mastoidectomy ($n = 4$) Canal wall down mastoidectomy ($n = 4$)

ND no data

^aPatients population report by Soudry et al. [9] are included in the case series of Stern Shavit et al. [4]

with consideration to physical findings, pain assessment and the patient's general condition. Laboratory findings such as erythrocyte sedimentation rate and C-reactive protein taken during treatment were also considered and have been mentioned previously in the evaluation of clinical response [11].

Aggressive or advanced disease Advanced disease has also been reported as an indication for surgical intervention. Soudry et al. [12] reported a group of 11 patients with aggressive NOE, all of whom required surgery. In their study prognostic factors associated with advanced disease included facial nerve paralysis, bilateral disease and advanced radiological findings (temporomandibular joint bone destruction, soft tissue involvement in the infratemporal fossa or nasopharynx). Within this group, five patients died from disease. Stevens et al. [13] defined advanced NOE based on radiological findings, clinical findings and involvement of cranial nerves. Advanced disease was associated with higher adverse disease-specific outcome and a higher mortality rate. As a result, they suggest earlier surgical intervention in such cases. Based on Soudry's classification, five of our patients (25%) exhibited clinical and radiological signs of aggressive disease (see Table 2—patients number 10, 13, 7, 19, 20). Surgical findings included facial canal involvement ($n = 3$) and TMJ involvement ($n = 1$), indicating a relatively extensive

disease in comparison to the other patients that underwent surgery. Our surgical findings support this stratification of patients and we feel that surgeons should consider a more aggressive initial approach in patients with clinical and radiological features of aggressive disease.

Facial nerve paralysis Isolated facial nerve paralysis is another relative indication for surgery and has been defined also as part of extensive or aggressive NOE. Although cranial nerve involvement is commonly seen as part of aggressive NOE, facial nerve palsy may also be seen in the absence of other clinical or radiological signs of advanced disease. This might be due to local bone involvement and it is possible that conservative treatment is sufficient. Soudry et al. [9] reported on a group of 48 NOE patients including 8 patients with facial nerve paralysis, among them 4 were operated. In his study, facial nerve paralysis was not associated with a worse outcome. It is important to note, however, that no data were reported within the surgical subgroup in regards to peri-operative findings, post-operative facial nerve function and outcome. In our study, two patients with facial nerve paralysis underwent surgical intervention, one with HRTBCT signs of advanced disease (see Table 2; patient 20), and one with no other clinical or radiological findings (see Table 2; patient 19). Disease control with only partial facial nerve function was achieved in both. Due to the small patient number it is difficult to conclude on the contribution

of surgical intervention in cases of facial paralysis. One may consider that the palsy reflects temporal bone involvement and decompression is not required. In these cases patients might be treated conservatively.

Deep tissue sterile culture Obtaining deep tissue sterile cultures has also been reported as a relative indication for surgical intervention [2, 3, 14]. In our study, obtaining deep tissue culture was not considered as a main indication for surgery. Among the five deep tissue culture results retrieved (see Table 2—patients number 12, 14, 15, 18, 20), one patient exhibited a different pathogen compared to the initial swab and this did not change substantially the treatment regimen given. Gruber et al. [3] reported on the use of deep tissue PCR evaluation in three patients with sterile culture NOE. In all three patients fungal pathogen was isolated. We have no experience with PCR analysis of the biopsied tissue, however, based on Gruber's results this approach should be considered when cultures are sterile and response to empirical treatment is poor.

HRTBCT findings and extent of surgery

In review of the literature, it seems that the extent of surgery required depends on the disease behavior, clinical response to conservative treatment and radiological findings. Additionally, the patient's comorbidities and his or her ability to withstand prolonged surgery may further affect surgical planning. The available surgical procedures include local debridement with/without deep tissue biopsies [2, 3], mastoidectomy (canal wall up/canal wall down) [4], facial nerve decompression and petrosectomy [14]. Previous studies reported on the role of HRTBCT and its association with disease severity. Peleg et al. [10] reported that HRTBCT performed at admission correlated with clinical course. Soudry et al. [12] reported that HRTBCT findings of temporomandibular joint destruction and soft tissue involvement in the infratemporal fossa or nasopharynx were associated with aggressive disease.

In contrast to previous studies, we evaluated clinical and HRTBCT findings at admission, as well as the perioperative findings. Interestingly, three patients with middle ear bone erosion seen on HRTBCT did not undergo mastoidectomy and had complete disease resolution with the use of

Table 4 Suggested principles in preoperative planning on the type and extent of surgical management

Indication for surgery	HRTBCT finding	Peri-operative find	Suggested surgical extent
Lack of response to conservative treatment	No bone involvement	EEC granulation tissue	EEC local debridement
	Bone erosion of EEC canal	EEC bone erosion	EEC local debridement + canalplasty
	mastoid and/or middle ear soft tissue involvement with no bone involvement	EEC granulation tissue	EEC local debridement
	mastoid and/or middle ear soft tissue involvement with no bone involvement	EEC granulation tissue with bone erosion Extensive soft tissue involvement	EEC local debridement + canalplasty + CWU mastoidectomy
	middle ear bone erosion of a single site	EEC granulation tissue	EEC local debridement
	middle ear bone erosion ≥ 2 sites	Confirmed at surgery	EEC local debridement + CWU mastoidectomy Tympanoplasty ^a Ossiculoplasty ^a
Aggressive disease (advanced radiological involvement with/without cranial nerve dysfunction)	Varies in sites involved and in extent	Varies in sites involved and in extent	Mastoidectomy (CWU or CWD) and extension of surgery according to involvement Tympanoplasty ^a Ossiculoplasty ^a
Facial nerve Palsy (in the absence of other aggressive features)	Varies in sites involved and in extent	Possible but not mandatory bone erosion anywhere in the facial canal	Consider: CWD mastoidectomy with facial nerve decompression Conservative treatment
Deep biopsies	Varies in sites involved and in extent	EEC granulations	EEC local debridement extension of surgery according to involvement

HRTBCT high-resolution temporal bone computer tomography, *CWU* canal wall up, *CWD* canal wall down, *EEC* external ear canal

^aAs indicated

local debridement and post-operative antibiotic treatment. Furthermore, among the four patients within the tympanomastoid surgery group who exhibited radiological signs of bone erosion limited to a single site in the middle ear, gross evidence of bone involvement was seen in only two patients (50%). This might suggest that in selected cases where minimal bone erosion is seen on HRTBCT, soft tissue debridement followed by post-operative antibiotic treatment can be sufficient to achieve disease control. Among the four patients with radiological signs of middle ear bone erosion involving two subsites or more, three patients had perioperative findings indicating gross bone involvement. Despite the small patient number, we feel that extensive bone erosion requires CWU mastoidectomy as the minimal surgical procedure, and should be converted to CWD mastoidectomy in cases of severe bone erosion of the posterior canal wall and when better exposure of the middle ear is required. Table 4 summarizes the options of surgery according to the different indications.

Conclusions

We describe a unique group of NOE patients that underwent surgery. There seems to be a subset of patients with NOE who may benefit from surgery. In cases of non-responsive patients for a period of at least two weeks, surgery should be seriously considered. Mild middle ear HRTBCT findings might be addressed with local debridement, followed by post-operative antibiotic treatment. In non-responsive patients, with HRTBCT indicating an extensive temporal bone involvement, surgery should be considered, with surgical extent tailored to the sites of involvement.

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References

- Mader JT, Love J (1982) Malignant external otitis. *Arch Otolaryngol* 108:38–40
- Hollis S, Evans K (2011) Management of malignant (necrotising) otitis externa. *J Laryngol Otol* 125:1212–1217
- Gruber M, Roitman A, Doweck I et al (2014) Clinical utility of a polymerase chain reaction assay in culture-negative necrotizing otitis externa. *Otol Neurotol* 733–736:2015
- Stern Shavit S, Soudry E, Hamzany Y, Nageris B (2016) Malignant external otitis: factors predicting patient outcomes. *Am J Otolaryngol* 37:425–430
- Visosky AM, Isaacson B, Oghalai JS (2006) Circumferential petrosectomy for petrous apicitis and cranial base osteomyelitis. *Otol Neurotol* 27:1003–1013
- Peled C, El-Seid S, Bahat-Dinur A, Tzvi-Ran LR, Kraus M, Kaplan D (2019) Necrotizing otitis externa-analysis of 83 cases: clinical findings and course of disease. *Otol Neurotol* 40:56–62
- Cohen D, Friedman P (1987) The diagnostic criteria of malignant external otitis. *J Laryngol Otol* 101:216–221
- Peled C, Kraus M, Kaplan D (2018) Diagnosis and treatment of necrotizing otitis externa and diabetic foot osteomyelitis—similarities and differences. *J Laryngol Otol* 132:1–5
- Soudry E, Joshua BZ, Sulkes J, Nageris BI (2007) Characteristics and prognosis of malignant external otitis with facial paralysis. *Arch Otolaryngol Head Neck Surg* 133:1002–1004
- Peleg U, Perez R, Raveh D, Berelowitz D, Cohen D (2007) Stratification for malignant external otitis. *Otolaryngol Head Neck Surg* 137:301–305
- Loh S, Loh WS (2012) Malignant otitis externa: an Asian perspective on treatment outcomes and prognostic factors. *Otolaryngol Head Neck Surg* 148:991–996
- Soudry E, Hamzany Y, Preis M, Joshua B, Hadar T, Nageris BI (2011) Malignant external otitis: analysis of severe cases. *Otolaryngol Head Neck Surg* 144:758–762
- Stevens SM, Lambert PR, Baker AB, Meyer TA (2015) Malignant otitis externa: a novel stratification protocol for predicting treatment outcomes. *Otol Neurotol* 36:1492–1498
- Mahdyoun P, Pulcini C, Gahide I, Raffaelli C, Savodelli C, Castillo L, Guevara N (2013) Necrotizing otitis externa: a systematic review. *Otol Neurotol* 34:620–629
- Salit IE, McNeely DJ, Chait G (1985) Invasive external otitis: review of 12 cases. *Can Med Assoc J* 132:381–384
- Sade J, Lang R, Goshen S, Kitzes-Cohen R (1989) Ciprofloxacin treatment of malignant external otitis. *Am J Med* 87:138S–S141
- Lang R, Goshen S, Kitzes-Cohen R, Sade J (1990) Successful treatment of malignant external otitis with oral ciprofloxacin: report of experience with 23 patients. *J Infect Dis* 161:537–540
- Pedersen HB, Rosborg J (1997) Necrotizing external otitis: aminoglycoside and beta-lactam antibiotic treatment combined with surgical treatment. *Clin Otolaryngol Allied Sci* 22:271Y4
- Berenholz L, Katzenell U, Harell M (1619Y) Evolving resistant pseudomonas to ciprofloxacin in malignant otitis externa. *Laryngoscope* 112:1619Y22
- Lee S, Hooper R, Fuller A, Turlakow A, Cousins V, Nouraei R (2008) Otogenic cranial base osteomyelitis: a proposed prognosis-based system for disease classification. *Otol Neurotol* 29:666–672

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