Review

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Review

The Issue of Extrusion and Dislocation in Titanium Middle Ear Prostheses: A Literature Review

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Abstract: Titanium middle ear prostheses are widely used in surgical practice due to their acoustic properties. However, they present a significant drawback shared by all synthetic materials currently in use for middle ear reconstruction: they can be rejected by the organism of the host. In this study, we aim to review the current literature on titanium TORP and PORP extrusion and dislocation. Eighty-one articles were analysed after full article review based on the inclusion and exclusion criteria. The most common indication for reconstruction was chronic otitis media with cholesteatoma. The average extrusion or dislocation rate was 5.1%, ranging from 0 to 35%. The average improvement in air-bone gap was 12.3 dB (1.6 dB to 25.1 dB) and 13.7 (-0,5 dB to 22.7 dB) for PORP ad TORP groups, respectively. The data reported on this topic are highly variable, demonstrating the functional outcomes are difficult to predict in clinical practice. We believe the current limitations could be overcome with technological developments, including bioengineering research focused on promoting the prothesis adaptation to the ME environment.

Keywords: middle ear; ossicular replacement prosthesis; titanium; extrusion; dislocation; complication; hearing

1. Introduction

The restoration of hearing conduction entwined within the eradication of middle ear (ME) pathologies represent an outstanding goal of modern otosurgery. Indeed, with the demands of today's fast paced society based on communication and rapid interactions, adequate social hearing is essential. As is well known, hearing loss leads to communication difficulties and social isolation. In addition to this, effortful listening increases energy required for processing and comprehending the auditory signal, thus diverting cognitive resources from other mental tasks[1]. Historically, the disadvantages of monaural compared with binaural hearing have not been stressed in audiological debate. Otherwise, current literature agrees hearing rehabilitation involves restoration of binaural stimulation. Indeed, central auditory pathway combine and compare the raw information from the two cochleae addressing complex tasks such as sound localization and speech perception in demanding listening environments[2]. While, since the 1990s to date technologies which bypass the ME sound-conducting mechanism have spread onto the market[3],[4], ossiculoplasty and passive ME implants continue to be widely used and studied. Several materials and techniques have been adopted over the years for ossicular reconstruction, with varying degrees of success. When available, autologous material refashioned to provide customized interposition is the prime source of repair[5]. In the last three decades, many alloplastic materials have been tested as suitable ossicular replacements, such as metals, ceramics, and plastics. Depending upon the defects to be reconstructed, synthetic prostheses are distinguished between Partial Ossicular Replacement Prostheses (PORP), mounted upon the intact stapes, and Total Ossicular Replacement Prostheses (TORP) for cases with no stapes superstructure[6]. At the present time, titanium is widely used for its physical properties, being lightweight with high stiffness and allowing easy individual adaptation to anatomical variations. In current literature numerous studies focus on hearing outcomes with titanium prostheses, demonstrating the reliably of this material in restoring conduction mechanism[7]. On the other hand, the rate of complications to be expected represent a notable aspect in presurgical counselling, regarding which the reported data are often conflicting. We aim to review the existing literature about complications of titanium prostheses ossicular reconstruction, with particular regard to extrusion and dislocation, and to discuss the current clinical perspectives.

2. Materials and Methods

A search of the literature was performed in the PUBMED database. The strategy used was based on the "Preferred Reporting Items for Systematic Reviews and Meta-analyses" (PRISMA) guidelines. The research was conducted using the following keywords: "((TORP) OR (PORP) OR (ossicular replacement) OR (ossiculoplasty)) AND titanium". The population of interest was patients who had undergone ossiculoplasty with titanium PORP or TORP. There was no limitation in age, sex, or follow-up periods. The studies also had to include data about complications, namely prosthesis extrusion or dislocation focusing on cases not related to recurrence of cholesteatoma. Only articles in English were included. Review articles, letters, editorials and case reports were omitted. Exclusion criteria also applied to animal research and cadaver studies. In the included articles we considered the postoperative improvement in air-bone gap (ABG) as a secondary outcome.

3. Results

A PRISMA flow chart illustrating both the search numbers and included studies is schematically presented in Figure 1. A total of 311 records ware identified. However, after excluding articles written in languages other than English, editorials, letters to editors, case reports, and reviews, 243 studies were considered. A preliminary selection was based on titles and abstracts: 127 papers were evaluated for full text review, of which 41 did not meet the inclusion criteria and 5 additional records were excluded because the full text was unavailable. 81 articles were included in the review and were further analysed. The selected articles covered 7269 subjects and 7366 ME implants, including 3638 PORP and 3728 TORP. The demographic characteristics are displayed in Table 1. In 6 studies the average age was less than 18 years. The most common indication for reconstruction was chronic otitis media with cholesteatoma (CCOM, 34,1%), followed by chronic otitis media without cholesteatoma (COM, 16,2%). The indication was generically expressed as chronic otitis media in 2300 cases. Surgical details and functional outcomes are shown in Table 2. The average improvement in ABG for PORP was 12.3 dB, ranging from 1.6 dB to 25.1 dB. The average change in ABG for TORP was 13.7 (range from -0,5 dB to 22.7 dB). The average extrusion or dislocation rate was 5.1% (reported in 62 articles) ranging from 0 to 35%. Considering the six articles in which the average age was less than 18 years, the extrusion or dislocation rate in this limited cohort was 13.7%. The onset of complications is mentioned in only 16 articles, ranging from 2 months to 8 years. Their treatment is cited in 32 articles, in all cases except one the management consisted of surgical revision. The mean follow-up time was less than or equal to 12 months in 30 studies, among which the 25.4% of complications were reported.

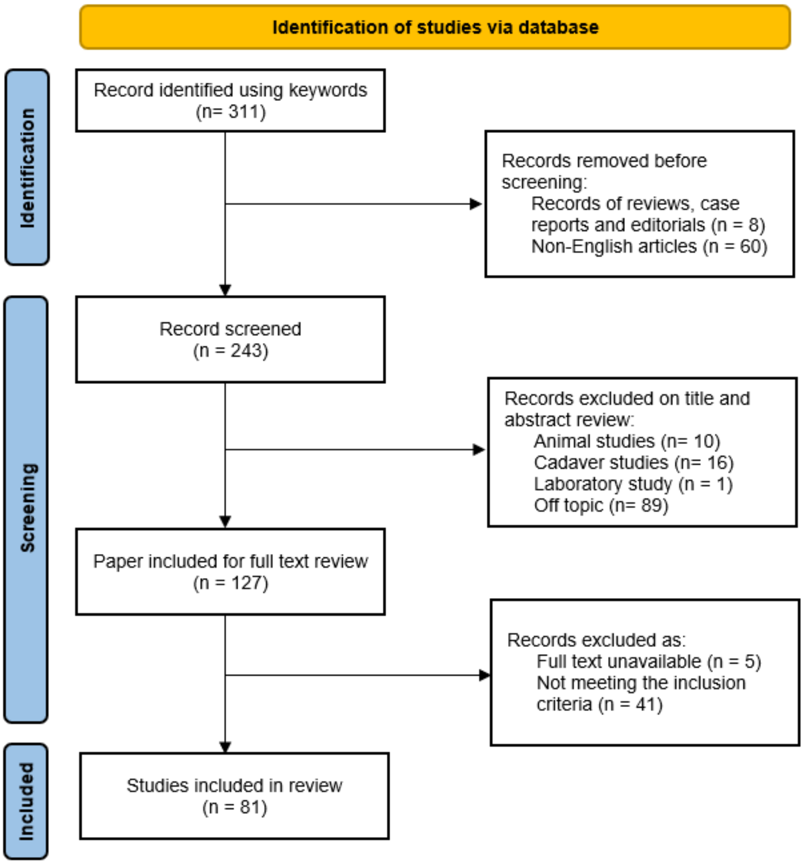

Figure 1. PRISMA 2020 based flow-diagram showing review search.

Table 1. Demographics and clinical data.

Authors, year	Pts	Ears	PORP	TORP	Age at surgery (range)	Middle ear disorder
Wang et al. 1999[8]	113	124	86	38	n.a.	59 CCOM, 54 COM, 2 CA, 9 TS
Dalchow et al. 2001[9]	1304	1304	647	657	5- 82y	1304 COM + CCOM
Krueger et al. 2002[10]	31	31	16	15	n.a.	31 CCOM + COM
Hillman and Shelton. 2003[11]	53	53	30	23	34.8y	n.a.
Ho et al. 2003[12]	25	25	14	11	45y (14–74)	15 CCOM, 6 COM, 4 CA
Neff et al. 2003[13]	18	18	0	18	37y (8 - 80)	11 CCOM, 7 COM+TS
Neumann et al. 2003[14]	59	61	27	34	36y (7-81)	32 CCOM, 11 COM, 16 AT, 2 TS
Fisch et al. 2004[15]	46	46	0	46	44.8y (22-65)	19 CCOM, 20 COM, 7 CA + TR
Gardner et al. 2004[16]	149	149	111	38	32.5 y (3-75)	77 CCOM, 40 COM, 32 n.a.
Martin et al. 2004[17]	68	68	30	38	39y (6-74)	68 CCOM+ COM
Menéndez-Colino et al. 2004[18]	23	23	0	23	37y (8-65)	17 CCOM, 3 COM, 1 AT, 2 CA
Lehnerdt et al. 2005[19]	15	15	14	1	12y (n.a.)	15 CCOM + COM
De Vos et al. 2006[20]	129	140	65	75	37y (3-73)	72 CCOM, 12 COM, 17 AT, 16 TS, 23 n.a.
Vassbotn et al. 2006[21]	71	73	38	35	31.5 y	40 CCOM, 4 COM. 29 CA
Schmerber et al. 2006[22]	111	111	61	50	38.4 y (7 – 76)	82 CCOM, 16 COM, 4 AT, 5 CA, 1 OTO, 3 TR
Hales et al. 2007[23]	34	34	24	10	26y (4-59)	29 CCOM, 5 n.a.
Siddiq and Raut. 2007[24]	33	33	20	13	35.9 y (7 - 64)	15 CCOM, 18 COM
Truy et al. 2007[25]	62	62	27	35	37.5y (n.a.)	38 CCOM, 24 n.a.
Coffey et al. 2008[26]	80	80	29	51	28.8y (n.a.)	35 CCOM, 36 COM, 3 CA, 4 OTO, 2 TR
Michael et al. 2008[27]	14	14	9	5	11y (7-14)	6 CCOM, 4 COM, 3 AT, 1 n.a.
Redaelli de Zinis. 2008[28]	26	26	12.	14.	49y (17-78)	26 CCOM
Alaani and Raut. 2009[29]	97	97	65	32	39.6 y (5 –75)	40 CCOM, 10 COM, 38 AT, 9 n.a.
Colletti et al. 2009[30]	19	19	0	19	50 y (19 - 76)	19 COM
Roth et al. 2009[31]	54	54	32	22	34y (6-74)	36 CCOM, 9 COM, 4 CA, 5 TR
Woods et al. 2009[32]	70	70	40	30	34.1y (11-76)	33 CCOM, 12 COM, 10 AT, 15 n.a.
Fong et al. 2010[33]	51	51	34	17	38 y (7 – 69)	20 CCOM, 31 COM
Inũiguez-Cuadra et al. 2010[34]	85	94	0	94	n.a.	n.a.
Luers et al. 2010[35]	70	70	0	70	43.6y (6-66)	40 CCOM, 30 COM
Praetorius et al. 2010[36]	14	14	14	0	50.4y (13–74)	14 CCOM
Quesnel et al. 2010[37]	74	74	27	47	11.3y (n.a.)	n.a.
Yung and Smith. 2010[38]	49	49	19	30	44y (n.a.)	14 CCOM, 35 COM
Babighian and Albu. 2011[39]	125	125	0	125	43.7 (n.a.)	125 CCOM
Beutner et al. 2011[6]	18	18	18	0	44.4y (8-69)	12 CCOM, 6 COM
Quaranta et al. 2011[37]	57	57	19	38	38 y (6 – 67)	57 CCOM
Mardassi et al. 2011[40]	70	70	37	33	43y (5-77)	47 CCOM, 23 COM
Nevoux et al. 2011[41]	114	116	0	116	9.8y (n.a)	116 CCOM
Berenholz et al. 2013[42]	152	152	84	68	47.3y (n.a.)	92 CCOM, 56 COM, 4 n.a.
Gostian et al. 2013[43]	12	12	0	12	42y (9 - 73)	8 CCOM, 4 COM
Hess-Erga et al. 2013[44]	76	76	44	32	33y (6-78)	40 CCOM, 5 COM, 31 TR
Meulemans et al 2013[45]	83	89	89	0	n.a. (7-85)	51 CCOM, 21 COM, 17 n.a.
Shah et al. 2013[46]	19	19	15	4	14–50y (n.a.)	19 CCOM + COM
Birk et al. 2014[47]	60	62	62	0	38y (4 - 83)	n.a.
Fayad et al. 2014[48]	62	62	0	62	38.4y (3 - 82)	60 COM, 2 n.a.
Órfão et al. 2014[49]	43	43	26	17	39y (7- 70)	14 CCOM, 17 COM, 12 n.a.
Pringle et al. 2014[50]	73	73	36	37	32.9y (6 - 64)	n.a.
Baker et al. 2015[51]	79	83	56	27	37.3y (6–79)	74 CCOM+ COM, 9 n.a.
Boleas-Aguirre et al. 2015[52]	16	16	0	16	56y (57–40)	8 CCOM+COM, 5 TS, 3 OTO
Lee et al. 2015[53]	27	27	18	9	54y (14 - 76)	17 CCOM, 10 COM
Ocak et al. 2015[54]	18	18	8	10	35.2y (13 - 57)	18 CCOM+ COM
Roux et al. 2015[55]	68	68	32	36	34.5y (13-56)	68 CCOM
Wolter et al. 2015[56]	71	75	0	75	14.3 y (7 - 18)	66 CCOM, 2 CA, 7 n.a.
Faramarzi et al. 2016[57]	45	45	0	45	n.a.	10 CCOM, 3 COM, 11 TS, 21 n.a.
Gostian et al. 2016[58]	47	47	47	0	43y (7–73)	17 CCOM, 30 COM

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Gostian et al. 2016[59]	42	42	0	42	42.8y (6-78)	26 CCOM, 16 COM
O'Connell et al. 2016[60]	149	149	56	93	30.1y (n.a.)	80 CCOM, 69 COM
Amith and Rs. 2017[61]	20	20	20	0	25 y (12 - 52)	10 CCOM, 10 COM
Govil et al. 2017[62]	101	101	47	54	9.8y (3.4-17.3)	n.a.
McMullen et al. 2017[63]	71	71	23	48	26y (6-73)	n.a.
Mulazimoglu et al. 2017[64]	126	126	126	0	37 y (7 –72)	86 CCOM, 11 COM, 13 CHL, 11 TR, 3 TS, 2 TU
Choi and Shin. 2018[65]	45	45	20	25	n.a.	45 CCOM + COM
Kahue et al. 2018[66]	130	130	130	0	36 y (n.a.)	121 COM, 9 TR
Kong et al. 2017[67]	20	20	9	11	49 y (n.a.)	n.a.
Kumar et al. 2017[68]	37	37	31	6	31.6 y (13-48)	37 CCOM+ COM
Lahlou et al. 2018[69]	256	280	163	117	44y (17 - 74)	125 CCOM, 85 COM, 40 AT, 4 CA, 11 OTO, 12 TR, 3 TU
Saliba et al. 2018[70]	158	158	0	158	29.7y (n.a.)	103 CCOM, 25 COM, 19 CA, 11 n.a.
Gu and Chi. 2019[71]	206	206	134	72	46y (12-70)	206 CCOM + COM
Haidar et al. 2019[72]	129	133	88	45	33 y (7 – 74)	34 COM, 10 AT, 24 GR, 65 n.a.
Potsangbam and Akoijam. 2019[5]	20	20	14	6	30y (8 - 64)	20 CCOM
Wood et al. 2019[73]	153	153	0	153	40y (6-89)	120 CCOM, 10 COM, 23 n.a.
Mantsopoulos et al. 2021[74]	274	274	274	0	38 y (6 – 67)	168 CCOM, 62 COM, 37 TS, 6 TR, 1 TU
Baazil et al. 2022[75]	106	106	0	106	35y (6.6–75.3)	105 CCOM+ COM, 1 CA
Bahmad and Perdigão. 2022[76]	13	13	0	13	44y (n.a.)	7 CCOM, 6 COM
Kraus et al. 2022[77]	36	38	38	0	40.4y (6-81)	18 CCOM, 20 COM
Park et al. 2022[78]	135	135	86	49	n.a.	94 CCOM, 41 COM
Plichta et al. 2022[79]	24	24	12	12	38.33 y (4-62)	24 TR
Van Hoolst et al. 2022[80]	99	113	0	113	n.a. (8 - 87)	74 CCOM, 15 COM, 24 CA
Chien et al. 2023[81]	8	8	8	0	n.a. (27-48)	8 TR
Faramarzi et al. 2023[82]	248	248	115	133	33 y (n.a.)	248 CCOM+COM+TS
Gülşen and Çıkrıkcı. 2023[83]	21	21	0	21	n.a. (28-44)	21 TS
Kálmán et al. 2023[84]	130	130	84	46	n.a.	130 CCOM+ COM
Kim et al. 2023[85]	130	130	78	52	49.2y (n.a.)	71 CCOM, 59 COM

Number of patients (pts): when not specified is assumed to be the same number of ears, years (y), not available (n.a.), chronic otitis media with cholesteatoma (CCOM), chronic otitis media without cholesteatoma (COM), atelectasis (AT), tympanosclerosis (TS), traumatic injuries (TR), otosclerosis (OTO), congenital abnormalities (CA).

Table 2. Surgical details and functional outcomes.

Authors, year	Surgery	Staging	Pre-op ABG		Post-op ABG		Extrusions and dislocations/ ears (%)	Onset	Treatment	Follow-up
			PORP	TORP	PORP	TORP				
Wang et al. 1999[8]	11 CWD, 48 CWU, 65 OPL	0	n.a.	n.a.	n.a.	n.a.	2/124 (1.6%)	n.a.	n.a.	12-46 mo
Dalchow et al. 2001[9]	n.a.	1100	n.a.	n.a.	14	15	29/1304 (2.2%)	n.a.	n.a.	6-72 mo
Krueger et al. 2002[10]	n.a.	n.a.	n.a.	n.a.	14.1	n.a.	0/31 (0%)	/	/	16 mo - 2 y
Hillman and Shelton. 2003[11]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2/53 (3.8%)	12 mo	surgical	3mo-n.a.
Ho et al. 2003[12]	9 CDW, 15 CWU, 1 OPL	20	38.7	42.8	18.1	21.5	1/25 (4%)	n.a.	surgical	6 mo
Neff et al. 2003[13]	16 OPL, 2 n.a.	6	n.a.	33.9	n.a.	16.9	0/ 18 (0%)	/	/	8 mo

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Neumann et al. 2003[14]	n.a.	0	n.a.	n.a.	n.a.	n.a.	0/61 (0%)	/	/	38 mo
Fisch et al. 2004[15]	21 CWD, 25 CWU	46	/	41.9	/	20.7	0/46 (0%)	/	/	1-7 y
Gardner et al. 2004[16]	13 CWD, 68 CWU, 21 OPL, 47 n.a.	13	26	40	18.8	21.7	1/149 (0.7%)	n.a.	n.a.	1.5y
Martin et al. 2004[17]	14 CWD, 7 CWU, 47 OPL	4	34	34	17	25	1/68 (1.5%)	n.a.	surgical	3 mo-2.5y
Menéndez-Colino et al. 2004[18]	16 CWD, 7 CWU	0	/	n.a.	/	n.a.	0/23 (0%)	/	/	18 mo
Lehnerdt et al. 2005[19]	n.a.	0	n.a.	n.a.	n.a.	n.a.	1/15 (6.6%)	n.a.	n.a.	6 mo
De Vos et al. 2006[20]	8 CWD, 65 CWU, 67 OPL	24	32.7	42.5	18.1	19.8	11/140 (7.9%)	22 mo	surgical	11.8 mo
Vassbotn et al. 2006[21]	20 CWD, 53 CWU	0	28	38	9	19	4/73 (5.5%)	n.a.	2 surgical, 2 n.a.	14.2 mo
Schmerber et al. 2006[22]	18 CWD, 93 CWU	65	n.a.	n.a.	15	26.5	14/111 (12.6%)	1: 17 mo, 1: 20 mo, 12 n.a.	13 surgical, 1 refused	20.5 mo
Hales et al. 2007[23]	4 CWD, 30 CWU	34	n.a.	n.a.	n.a.	n.a.	2/34 (5.9%)	n.a.	n.a.	19 mo
Siddiq and Raut. 2007[24]	5 CWD, 14 CWU, 14 n.a.	n.a.	25.1	23.3	15.3	13.4	0/33 (0%)	/	/	6 - 18 mo
Truy et al. 2007[25]	n.a.	n.a.	30.9	28	19.4	18.3	2/62 (3.2%)	2 mo	surgical	12 mo
Coffey et al. 2008[26]	22 CDW, 22 CWU, 30 OPL	34	n.a.	n.a.	14.3	16.0	3/80 (3.8%)	n.a.	n.a.	14.9 mo
Michael et al. 2008[27]	7 CWD, 3 CWU, 4 OPL	7	n.a.	n.a.	n.a.	n.a.	0/7 (0%)	/	/	12 mo

Redaelli de Zinis. 2008[28]	26 CWD	0	n.a.	n.a.	n.a.	n.a.	0/ 14 (0%)	/	/	12 mo
Alaani and Raut. 2009[29]	57 CWD, 40 CWU + OPL	29	26.3	32.1	10.6	14.8	2/97 (2.1%)	1 y	1 surgical, 1 n.a.	1 y
Colletti et al. 2009[30]	19 CWU	n.a.	/	40.7	/	21.5	3/19 (15.8%)	n.a.	2 surgical, 1 n.a.	36 mo
Roth et al. 2009[31]	11 CWD, 27 CWU, 16 OPL	29	31.0	38.2	13.3	16.4	1/54 (1.8%)	/	surgical	1-5 y
Woods et al. 2009[32]	n.a.	3	32.2	39.2	26.9	29.2	11/70 (15.7%)	n.a.	n.a.	6 mo
Fong et al. 2010[33]	4 CWD, 47 CWU	n.a.	n.a.	n.a.	n.a.	n.a.	1/51 (2%)	n.a.	n.a.	12 mo
Inũiguez-Cuadra et al. 2010[34]	56 CWD, 38 CWU	n.a.	/	23.8	/	15.4	8/94 (8.5%)	n.a.	n.a.	38 mo
Luers et al. 2010[35]	33 CWD, 37 CWU	0	/	33.9	/	19.7	0/70 (0%)	/	/	2 mo
Praetorius et al. 2010[36]	n.a.	n.a.	26.6	/	15.2	/	0/14 (0%)	/	/	8 mo
Quesnel et al. 2010[37]	n.a.	49	30.2	36.6	20.8	22	5/74 (6.8%)	n.a.	n.a.	33 mo
Yung and Smith. 2010[38]	n.a.	7	29.2	32.5	16.2	20.7	8/49 (16.3%)	n.a.	n.a.	2y
Babighian and Albu. 2011[39]	125 CWD	125	/	44.9	/	22.3	2/125 (1.6%)	n.a.	n.a.	12 mo
Beutner et al. 2011[6]	11 CWD, 7 CWU	0	26.8	/	18.2	/	0/18 (0%)	/	/	6 mo
Quaranta et al. 2011[37]	57 CWU	57	36.7	45.3	24.1	27.2	6/57 (10.5%)	n.a.	surgical	24 mo
Mardassi et al. 2011[40]	70 CWU + OPL	24	27.2	32.8	15	19.5	4/70 (5.7%)	n.a.	surgical	9.8 mo
Nevoux et al. 2011[41]	116 CWU	116	/	41	/	22.4	17/116 (14.7%)	2: 1y, 6: 2 y, 5: 5y, 1: >5y, 3: n.a.	surgical	34 mo
Berenholz et al. 2013[42]	15 CWD, 50 CWU, 87 n.a.	16	32.5	30.6	11.9	15.8	10/152 (6.6%)	n.a.	surgical	4.3 y
Gostian et al. 2013[43]	1 CWD, 11 CWU	n.a.	/	26.6	/	18.8	0/12 (0%)	/	/	32 mo

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Hess-Erga et al. 2013[44]	31 OPL, 40 n.a.	n.a.	28	37	15	20	4/76 (5%)	<1y	2 surgical	5.2y
Meulemans et al 2013[45]	7 CWD, 65 CWU, 17 OPL	0	26.2	/	15.6	/	3/89 (3.4%)	/	surgical	13 mo
Shah et al. 2013[46]	19 CWU	0	n.a.	n.a.	n.a.	n.a.	0/19 (0%)	/	/	11.1y
Birk et al. 2014[47]	n.a.	n.a.	26.9	/	15.4	/	1/62 (1.6%)	n.a.	n.a.	7 mo
Fayad et al. 2014[48]	8 CWD, 21 CWU, 30 OPL, 3 n.a.	23	/	35.1	/	18	1/62 (1.6%)	1 y	n.a.	21.7 mo
Órfão et al. 2014[49]	1 CWD, 11 CWU, 31 OPL	0	32.8	37.1	21.9	25.7	1/43 (2%)	n.a.	n.a.	20 mo
Pringle et al. 2014[50]	9 CWD, 47 CWU, 17 OPL	52	n.a.	n.a.	n.a.	n.a.	5/73 (6.8%)	n.a.	surgical	6 - 96 mo
Baker et al. 2015[51]	n.a.	38	28.2	30.3	16.5	20.6	5/ 83 (6.0%)	n.a.	surgical	41.8 mo
Boleas-Aguirre et al. 2015[52]	2 CWD, 2 CWU, 12 OPL	n.a.	/	34	/	16.4	0/ 16 (0%)	/	/	12 mo
Lee et al. 2015[53]	15 CWD, 11 CWU, 1 OPL	n.a.	23	28	12	15	0/27 (0%)	/	/	6 mo
Ocak et al. 2015[54]	15 CWU, 3 OPL	n.a.	33.7	38	8.6	19	1/18 (5.5%)	12 mo	n.a.	38.5 mo
Roux et al. 2015[55]	68 CWU	19	23.5	31	19.5	26	0/68 (0%)	/	/	23 mo
Wolter et al. 2015[56]	n.a.	n.a.	/	44	/	30	1/75 (1.3%)	3.9 y	surgical	2.7 y
Faramarzi et al. 2016[57]	45 OPL	45	/	36	/	24.7	2/45 (4.4%)	n.a.	n.a.	6-12 mo
Gostian et al. 2016[58]	15 CWD, 32 CWU	n.a.	25.7	n.a.	16.8	n.a.	1/47 (2%)	/	/	6.5y
Gostian et al. 2016[59]	18 CWD, 24 CWU	0	/	33	/	22	2/42 (4.8%)	6 mo	surgical	6.8y
O'Connell et al. 2016[60]	n.a.	77	30.9	37.9	17.6	21.8	5/149 (3.2%)	n.a.	surgical	51.6 mo

Amith and Rs. 2017[61]	3 OPL, 17 n.a.	3	44.4	/	31.3	/	3/20 (15%)	n.a.	n.a.	12 mo
Govil et al. 2017[62]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	29/101 (29%)	1.3 y	surgical	2.2y
McMullen et al. 2017[63]	n.a.	50	n.a.	n.a.	n.a.	n.a.	1/71 (1.4%)	8 mo	conservative	10.2 mo
Mulazimoglu et al. 2017[64]	33 OPL, 93 n.a.	33	/	28.2	/	22.3	30/126 (23.8%)	26 mo	12 surgical, 18 n.a.	4.5 y
Choi and Shin. 2018[65]	n.a.	8	n.a.	n.a.	n.a.	n.a.	2/45 (4.4%)	/	/	12 mo
Kahue et al. 2018[66]	5 CWD, 77 CWU, 48 OPL	10	29	/	18	/	3/130 (2.3%)	25 mo	surgical	37 mo
Kong et al. 2017[67]	n.a.	n.a.	27.6	28.5	26	29	4/20 (20%)	n.a.	n.a.	27 mo
Kumar et al. 2017[68]	n.a.	0	32.1	37.5	26.3	21.6	1/37 (2.7%)	n.a.	n.a.	6 mo
Lahlou et al. 2018[69]	46 CWD, 74 CWU, 160 OPL	0	26	30	15	20	17/280 (6.1%)	n.a.	surgical	12 mo
Saliba et al. 2018[70]	36 CWD, 122 CWU	62	/	38	/	26.3	24/158 (15%)	n.a.	surgical	18 mo
Gu and Chi. 2019[71]	206 CWD	0	27.8	28	16.4	18.4	2/206 (1.0%)	/	/	30 mo
Haidar et al. 2019[72]	133 CWU	8	29.6	33.3	12.9	18.7	5/133 (2.3%)	n.a.	n.a.	6 mo
Potsangbam and Akoijam. 2019[5]	20 OPL	20	37.1	40.3	17.6	22.5	7/20 (35%)	4-8y	n.a.	3y
Wood et al. 2019[73]	24 CWD, 114 CWU, 15 OPL	14	/	37.5	/	24.9	1/153 (0.6%)	n.a.	surgical	44 mo
Mantsopoulos et al. 2021[74]	n.a.	n.a.	22.7	/	15.7	/	8/274 (2.9%)	n.a.	n.a.	4 mo
Baazil et al. 2022[75]	3 CWD, 33 CWU, 70 OPL	74	/	38.1	/	27.6	8/106 (7.5%)	n.a.	n.a.	11.7 mo
Bahmad and Perdigão. 2022[76]	13 CWD	n.a.	/	35.1	/	20.7	0/13 (0%)	/	/	6 mo
Kraus et al. 2022[77]	n.a.	0	21.8	/	10.5	/	2/38 (5.3%)	n.a.	n.a.	1-9 y
Park et al. 2022[78]	113 CWD, 22 CWU	0	28.1	28.1	18.4	23.5	1/135 (0.7%)	n.a.	n.a.	8.1 mo
Plichta et al. 2022[79]	24 OPL	n.a.	n.a.	n.a.	n.a.	n.a.	1/24 (4.1%)	n.a.	surgical	24 mo
Van Hoolst et al. 2022[80]	28 CWD, 23 OPL, 62 n.a.	n.a.	/	32.7	/	21.7	17/113 (15.0%)	n.a.	surgical	39 mo

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Chien et al. 2023[81]	8 OPL	0	25.9	/	10.8	/	0/8 (0%)	/	/	3.58 mo
Faramarzi et al. 2023[82]	248 OPL	248	34	37.6	21.2	24.6	7/248 (2.8%)	n.a.	n.a.	12.5 mo
Gülşen and Çıkrıkcı. 2023[83]	21 OPL	0	/	37.1	/	14.5	1/21 (4.8%)	n.a.	surgical	12 mo
Kálmán et al. 2023[84]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	11/130 (8.5%)	n.a.	surgical	8.8 mo
Kim et al. 2023[85]	130 OPL	130	n.a.	n.a.	n.a.	n.a.	10/130 (7.7%)	n.a.	n.a.	22.7 mo

Canal wall down (CWD), canal wall up (CWU), ossiculoplasty (OPL), years (y), months (mo), not available (n.a.). Data included in column "surgery" refer to the procedure performed at the time of ME implant positioning regardless of any previous surgery. In column "staging" we reported, when available, the number of ossicular reconstruction performed in a second stage procedure. In the columns preoperative ABG (pre-op ABG) and postoperative ABG (post-op ABG) n.a. indicates this outcome is not mentioned or audiometric results differentiated between PORP and TORP group are not available. "Extrusions and dislocations/ears (%)": we excluded extrusions and dislocations caused by cholesteatomas. The data included in the columns "Onset" and "Treatment" refer to the time of appearance and management of complications. "Follow-up" indicates the average follow-up or, when not available, its range.

4. Discussion

Considering the cognitive and psychosocial impact of hearing loss, its treatment is mandatory not only to restore the auditory perceptual skills but also to ameliorate the central management of cognitive resources[86]. In recent years, the interaction between hearing and cognitive processes has been studied through pupillometry. Indeed, pupil dilation response has demonstrated to be an indicator of mental processing load during listening effort[87]. Hence, the rehabilitation of hearing loss seems to be mandatory for optimization of the limited cognitive resource. Ossiculoplasty is a well-established surgical procedure intended to auditory rehabilitation, however its practical use still today collides with some technical issues. The ideal ossiculoplasty prosthesis should ensure hearing restoration as well as being safe and stably integrated into surrounding tissues. Titanium has demonstrated to be a reliable material in term of easy surgical manipulation and functional hearing results[26]. In a recent meta-analysis Kortebein et al. reported a rate of 70.7% of PORP and 57.1% of TORP patients with a postoperative ABG less than 20 dB[7]. Moreover, it is safe during magnetic resonance imaging both at 1.5 and 3 tesla, which could be necessary for the depiction of recuring cholesteatoma[88]. However, it is not free of postoperative complications such as dislocation or extrusion. To our knowledge, this is the first work that specifically analyses the existing literature about titanium TORP and PORP extrusion and dislocation rates. Kortebein and colleagues in their review have addressed this issue. However, they focused on articles presenting at least one audiometric outcome, with a 12-months minimum follow up, thus limiting the available data about complications[7]. On the other hand, with the present work we would provide a comprehensive overview about this topic. It can be argued the exclusion of extrusion or dislocation caused by cholesteatoma from the analysis to be a limit. However, we consider the presence of cholesteatoma in an operated ear a complication itself. Therefore, the decision was taken to avoid a possible misleading factor, focusing on the intrinsic issues of titanium prostheses. Moreover, we considered the rate of extrusion and dislocation for combined PORPs and TORPs because only few articles report complications separated for the two cohorts. Our literature review has demonstrated that the reported extrusion and dislocation rates vary greatly in literature, ranging from 0 to 35%, distributed over variable follow-up time. Interestingly, the 25.4% of the overall complications occurred in studies with mean follow-up time less than or equal to 12 months. The evaluation focused on the 6 paediatric studies has disclosed an increased complication rate in this cohort (13.7%) when compared to overall results (5.5%). We can speculate, as suggested by Michael and colleagues, a possible explanation to be the higher frequency of Eustachian tube dysfunction and of air way inflammation in pediatric population relative to adults[27]. Notably, the exiguity of details about the circumstances in which complications have occurred hampers a proper correlation with possible influencing factors, such as ME pathologies, surgical procedures or staging of treatment. Consistently, very few studies reported the onset time, thus allowing a limited discussion about this topic. The only remark which deserves to be underlined is the considerable variability of these findings, ranging from 2 months to 8 years.

The information about extrusions and dislocations treatment are limited, however we found a trend in favour of a surgical revision attempt. Unfortunately, the available data do not allow to trace any cases eventually managed with other rehabilitation strategies, such as the active ME prostheses. In addition, in our analysis we considered the preoperative and postoperative ABG as a secondary outcome, despite the presence of these data was not among inclusion criteria. Our findings are in agreement with those of Kortebein et al., who reported an ABG improvement of 12.1 and 16.7 dB after titanium PORP and TORP placement, respectively[7]. We disclosed a high variability in the average ABG improvement among the studies included in the present review. It should be noted the data presented in literature are widely heterogeneous and thus difficult to compare, with respect to titanium prostheses models, underlying ME diseases, surgical hands and techniques, and follow-up strategies. The average ABG improvement was 12.3 dB, ranging from 1.6 dB to 25.1 dB, for PORP group, and 13.7 dB, from -0,5 dB to 22.7 dB, for TORP group. The functional results depend on many factors including status of the ME environment and Eustachian tube disfunction. According to our review, the most common indication for ossicular reconstruction is represented by chronic otitis media. Indeed, recurrence or progression of the ME pathology can affect the outcomes of ossiculoplasty. Moreover, host tissues are reported to interact with the surface of the ME prosthesis inducing a foreign body inflammation with a possible consequential dislocation and extrusion, thus compromising the initial functional results[89]. We strongly believe these considerations should be integral part of preoperatory counselling. Furthermore, the patients should be aware titanium PORP and TORP, despite their satisfying audiologic results, present the technical limitations shared by all passive ME prostheses. Namely, they aim to restore a normal coupling between the tympanic membrane and the inner ear, thus allowing a non-reinforced transmission of incident sound waves.[90] In fact, they entail certain anatomical and functional prerequisites that limit their use to selected situations.[6] Currently, the active ME prostheses, as well as percutaneous or transcutaneous bone conduction implants, have been designed to overcome the abovementioned issues[6],[3]. Otherwise, these solutions imply higher costs and the discomfort of an external component. All in all, current technological developments place us on the horns of a dilemma: to shelve the experience of the titanium prostheses or strive to overcome their ME adaptability and functional limits, maybe with bioengineering tools?

5. Conclusions

Here, we present a comprehensive literature review focused on titanium TORP and PORP extrusion and dislocation. We believe the variability in the reported complication rates demonstrates the factors involved in determining the prostheses adaptability in ME are highly changeable and difficult to predict. We advocate further research that using current technology could overcome the existing limits of titanium ME PORP and TORP to exploit their advantage in clinical practice.

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References

1. Slade, K.; Plack, C.J.; Nuttall, H.E. The effects of age-related hearing loss on the brain and cognitive function. *Trends Neurosci* **2020**, 43, 810-821.
2. Avan, P.; Giraudet, F.; Büki, B. Importance of binaural hearing. *Audiol Neurootol* **2015**, 20 Suppl 1, 3-6.
3. Canzi, P.; Avato, I.; Beltrame, M.; Bianchin, G.; Perotti, M.; Tribi, L.; Gioia, B.; et al. Retrosigmoidal placement of an active transcutaneous bone conduction implant: surgical and audiological perspectives in a multicentre study. *Acta Otorhinolaryngol Ital* **2021**, 41, 91–99.

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4. Canzi, P.; Berrettini, S.; Albera, A.; Barbara, M.; Bruschini, L.; Canale, A.; Carlotto, E.; et al. Current trends on subtotal petrosectomy with cochlear implantation in recalcitrant chronic middle ear disorders. *Acta Otorhinolaryngol Ital* **2023**, 43, S67–S75.
5. Potsangbam, D.S.; Akoijam, B.A. Endoscopic transcanal autologous cartilage ossiculoplasty. *Indian J Otolaryngol Head Neck Surg* **2019**,71, 54-59.
6. Beutner, D.; Hüttenbrink, K.B. Passive and active middle ear implants. *GMS Curr Top Otorhinolaryngol Head Neck Surg* **2009**, 8, Doc09.
7. Kortebein, S.; Russomando, A.C.; Greda, D.; Cooper, M.; Ledbetter, L.; Kaylie, D. Ossicular chain reconstruction with titanium prostheses: a systematic review and meta-analysis. *Otol Neurotol* **2023,** 44, 107-114.
8. Wang, X.; Song, J.; Wang, H. Results of tympanoplasty with titanium prostheses. *Otolaryngol Head Neck Surg* **1999**, 121, 606-609.
9. Dalchow, C.V.; Grün, D.; Stupp, H.F. Reconstruction of the ossicular chain with titanium implants. *Otolaryngol Head Neck Surg* **2001**, 125, 628-630.
10. Krueger, W.W.; Feghali, J.G.; Shelton, C.; Green, J.D.; Beatty, C.W.; Wilson, D.F.; Thedinger, B.S.; Barrs, D.M.; McElveen, J.T. Preliminary ossiculoplasty results using the Kurz titanium prostheses. *Otol Neurotol* **2002**, 23, 836-839.
11. Hillman, T.A.; Shelton, C. Ossicular chain reconstruction: titanium versus plastipore. *Laryngoscope* **2003**, 113, 1731-1735.
12. Ho, S.Y.; Battista, R.A.; Wiet, R.J. Early results with titanium ossicular implants. *Otol Neurotol* **2003**, 24, 149-152.
13. Neff, B.A.; Rizer, F.M.; Schuring, A.G.; Lippy, W.H. Tympano-ossiculoplasty utilizing the Spiggle and Theis titanium total ossicular replacement prosthesis. *Laryngoscope* **2003**, 113, 1525-1529.
14. Neumann, A.; Schultz-Coulon, H.J.; Jahnke, K. Type III tympanoplasty applying the palisade cartilage technique: A study of 61 cases. *Otol Neurotol* **2003**,24, 33-37.
15. Fisch, U.; May, J.; Linder, T.; Naumann, I.C. A new L-shaped titanium prosthesis for total reconstruction of the ossicular chain. *Otol Neurotol* **2004,** 25, 891-902.
16. Gardner, E.K.; Jackson, C.G.; Kaylie, D.M. Results with titanium ossicular reconstruction prostheses. *Laryngoscope* **2004**, 114, 65-70.
17. Martin, A.D.; Harner, S.G. Ossicular reconstruction with titanium prosthesis. *Laryngoscope* **2004**, 114, 61-64.
18. Menéndez-Colino, L.M.; Bernal-Sprekelsen, M.; Alobid, I.; Traserra-Coderch, J. Preliminary functional results of tympanoplasty with titanium prostheses. *Otolaryngol Head Neck Surg* 2004, 131, 17-19.
19. Lehnerdt, G.; Van Delden, A.; Lautermann, J. Management of an "Ear Camp" for children in Namibia. *Int J Pediatr Otorhinolaryngol* **2005**, 69, 663-668.
20. De Vos, C.; Gersdorff, M.; Gérard, J.M. Prognostic factors in ossiculoplasty. *Otol Neurotol* **2006**, 28, 61-67.
21. Vassbotn, F.S.; Møller, P.; Silvola, J. Short-term results using Kurz titanium ossicular implants. *Eur Arch Otorhinolaryngol* **2007**, 264, 21-25.
22. Schmerber, S.; Troussier, J.; Dumas, G.; Lavieille, J.P.; Nguyen, D.Q. Hearing results with the titanium ossicular replacement prostheses. *Eur Arch Otorhinolaryngol* **2006,** 263, 347-354.
23. Hales, N.W.; Shakir, F.A.; Saunders, J.E. Titanium middle ear prostheses in staged ossiculoplasty: does mass really matter? *Am J Otolaryngol* **2007**, 28, 164-167.
24. Siddiq, M.A.; Raut, V.V. Early results of titanium ossiculoplasty using the Kurz titanium prosthesis - A UK perspective. *J Laryngol Otol* **2007**, 121, 539-544.
25. Truy, E.; Naiman, A.N.; Pavillon, C.; Abedipour, D.; Lina-Granade, G.; Rabilloud, M. Hydroxyapatite versus titanium ossiculoplasty. *Otol Neurotol* **2007**, 28, 492-498.
26. Coffey CS, Lee F, Lambert PR. Titanium versus nontitanium prostheses in ossiculoplasty. *Laryngoscope* **2008**, 118, 1650-1658.
27. Michael, P.; Fong, J.; Raut, V. Kurz titanium prostheses in paediatric ossiculoplasty- short term results. *Int J Pediatr Otorhinolaryngol* **2008**, 72, 1329-1333.
28. Redaelli De Zinis, L.O. Titanium vs hydroxyapatite ossiculoplasty in canal wall down mastoidectomy. *Arch Otolaryngol Head Neck Surg* **2008**, 134, 1283-1287.
29. Alaani, A.; Raut, V.V. Alaani A, Raut V V. Kurz titanium prosthesis ossiculoplasty — Follow-up statistical analysis of factors affecting one year hearing results. *Auris Nasus Larynx* **2010**, 37, 150-154.
30. Colletti, V.; Carner, M.; Colletti, L. TORP vs round window implant for hearing restoration of patients with extensive ossicular chain defect. *Acta Otolaryngol* **2009**, 129, 449-452.
31. Roth, J.A.; Pandit, S.R.; Soma, M.; Kertesz, T.R. Ossicular chain reconstruction with a titanium prosthesis. *J Laryngol Otol* **2009**, 123, 1082-1086.
32. Woods, O.; Fata, E.l.; Saliba, I. Ossicular reconstruction: incus versus universal titanium prosthesis. *Auris Nasus Larynx* **2009**, 36, 387-392.
33. Fong, J.C.; Michael, P.; Raut, V. Titanium versus autograft ossiculoplasty. *Acta Otolaryngol* **2010**, 130, 554-558.

34. Iñiguez-Cuadra, R.; Alobid, I.; Borés-Domenech, A.; Menéndez-Colino, L.M.; Caballero-Borrego, M.; Bernal-Sprekelsen, M. Type III tympanoplasty with titanium total ossicular replacement prosthesis: anatomic and functional results. *Otol Neurotol* **2010**, 31, 409-414.
35. Luers, J.C.; Huttenbrink, K.B.; Mickenhagen, A.; Beutner, D. A modified prosthesis head for middle ear titanium implants- experimental and first clinical results. *Otol Neurotol* **2010**, 31, 624-629.
36. Praetorius, M.; Kirchenbauer, S.S.; Buss, S.; Klingmann, C.; Plinkert, P.K.; Baumann, I. First experiences with a new adjustable length titanium ossicular prosthesis (ALTO). *Acta Otolaryngol* **2010,** 130, 1237-1241.
37. Quesnel, S.; Teissier, N.; Viala, P.; Couloigner, V.; Van Den Abbeele, T. Long term results of ossiculoplasties with partial and total titanium Vario Kurz prostheses in children. *Int J Pediatr Otorhinolaryngol* **2010**, 74, 1226-1229.
38. Yung, M.; Smith, P. Titanium versus nontitanium ossicular prostheses-a randomized controlled study of the medium-term outcome. *Otol Neurotol* **2010,** 31, 752-758.
39. Babighian, G.; Albu, S. Stabilising total ossicular replacement prosthesis for ossiculoplasty with an absent malleus in canal wall down tympanomastoidectomy - a randomised controlled study. *Clin Otolaryngol* **2011**, 36, 543-549.
40. Mardassi, A.; Deveze, A.; Sanjuan, M.; Mancini, J.; Parikh, B.; Elbedeiwy, A.; Magnan, J.; Lavieille, J.P. Titanium ossicular chain replacement prostheses: prognostic factors and preliminary functional results. *Eur Ann Otorhinolaryngol Head Neck Dis* **2011**, 128, 53-58.
41. Nevoux, J.; Moya-Plana, A.; Chauvin, P.; Denoyelle, F.; Garabedian, E.N. Total ossiculoplasty in children: predictive factors and long-term follow-up. *Arch Otolaryngol Head Neck Surg* **2011**, 137, 1240-1246.
42. Berenholz, L.P.; Burkey, J.M.; Lippy, W.H. Short- and long-term results of ossicular reconstruction using partial and total plastipore prostheses. *Otol Neurotol* **2013**, 34, 884- 889.
43. Gostian, A.O.; Pazen, D.; Luers, J.C.; Huttenbrink, K.B.; Beutner, D. Titanium ball joint total ossicular replacement prosthesis - Experimental evaluation and midterm clinical results. *Hear Res* **2013**, 301, 100-104.
44. Hess-Erga, J.; Møller, P.; Vassbotn, F.S. Long-term hearing result using Kurz titanium ossicular implants. *Eur Arch Oto-Rhino-Laryngology* **2013**, 270, 1817-1821.
45. Meulemans, J.; Wuyts, F.L.; Forton, G.E. Middle ear reconstruction using the titanium Kurz Variac partial ossicular replacement prosthesis: functional results. *JAMA Otolaryngol Head Neck Surg* **2013** 139, 1017-1025.
46. Shah, K.D.; Bradoo R.A.; Joshi A.A.; Sapkale, D.D. The efficiency of titanium middle ear prosthesis in ossicular chain reconstruction: our experience. *Indian J Otolaryngol Head Neck Surg* **2013,** 65, 298-301.
47. Birk, S.; Brase, C.; Hornung, J. Experience with the use of a partial ossicular replacement prosthesis with a ball-and-socket joint between the plate and the shaft. *Otol Neurotol* **2014**, 35, 1248-1250.
48. Fayad, J.N.; Ursick, J.; Brackmann, D.E.; Friedman, R.A. Total ossiculoplasty: short- and long- term results using a titanium prosthesis with footplate shoe. *Otol Neurotol* **2014**, 35, 108- 113.
49. Órfão, T.; Júlio, S.; Ramos, J.F.; Dias, C.C.; Silveira, H.; Santos, M. Audiometric outcome comparison between titanium prosthesis and molded autologous material. *Otolaryngol Head Neck Surg* **2014**, 151, 315-320.
50. Pringle, M.B.; Sunkaraneni, V.S.; Tann, N. Is cartilage interposition required for ossiculoplasty with titanium prostheses? *Otol Neurotol* **2014**, 35, 482-488.
51. Baker, A.B.; O'Connell, B.P.; Nguyen, S.A.; Lambert, P.R. Ossiculoplasty with titanium prostheses in patients with intact stapes: comparison of TORP versus PORP. *Otol Neurotol* **2015**, 36, 1676-1682.
52. Boleas-Aguirre, M.S.; Ruiz de Erenchun-Lasa, I.; Bulnes-Plano, M.D. Audiological results after total ossicular reconstruction for stapes fixation. *Eur Arch Otorhinolaryngol* **2015,** 272, 3123-3130.
53. Lee, J.I.; Yoo, S.H.; Lee, C.W.; Song C.l.; Yoo, M.H.; Park, H.J. Short-term hearing results using ossicular replacement prostheses of hydroxyapatite versus titanium. *Eur Arch Otorhinolaryngol* **2015,** 272, 2731-2735.
54. Ocak, E.; Beton, S.; Meço, C.; Dursun, G. Titanium versus Hydroxyapatite prostheses: comparison of hearing and anatomical outcomes after ossicular chain reconstruction. *Turk Arch Otorhinolaryngol* **2015**, 53, 15-18.
55. Roux, A.; Bakhos, D.; Villeneuve, A.; Hermann, R.; Suy, P.; Lescanne, E.; Truy, E. Does checking the placement of ossicular prostheses via the posterior tympanotomy improve hearing results after cholesteatoma surgery? *Otol Neurotol* **2015**, 36, 1499-1503.
56. Wolter, N.E.; Holler, T.; Cushing, S.L.; Chadha, N.K.; Gordon, K.A.; James, A.L.; Papsin, B.C. Pediatric ossiculoplasty with titanium total ossicular replacement prosthesis. *Laryngoscope* **2015**, 125, 740-745.
57. Faramarzi M, Jahangiri R, Roosta S. Comparison of Titanium vs. Polycel total ossicular replacement prosthesis. Iran J Otorhinolaryngol. 2016;28(2):89-97.
58. Gostian, A.O.; Kouame, J.M.; Bremke, M.; Ortmann, M.; Hüttenbrink, K.B.; Beutner, D. Long term results of the titanium clip prosthesis. *Eur Arch Otorhinolaryngol* **2016**, 273, 4257-4266.
59. Gostian, A.O.; Kouamé, J.M.; Bremke, M.; Ortmann, M.; Hüttenbrink, K.B.; Beutner, D. Long-term results of the cartilage shoe technique to anchor a titanium total ossicular replacement prosthesis on the stapes footplate after type III tympanoplasty. *JAMA Otolaryngol Head Neck Surg* **2016**, 142, 1094-1099.

60. O'Connell, B.P.; Rizk, H.G.; Hutchinson, T.; Nguyen, S.A.; Lambert, P.R. Long-term outcomes of titanium ossiculoplasty in chronic otitis media. *Otolaryngol Head Neck Surg* **2016**, 154, 1084-1092.
61. Amith N, RS M. Autologous incus versus titanium partial ossicular replacement prosthesis in reconstruction of Austin type A ossicular defects: A prospective randomised clinical trial. *J Laryngol Otol* **2017**, 131, 391-398.
62. Govil, N.; Kaffenberger, T.M.; Shaffer, A.D.; Chi, D.H. Factors influencing hearing outcomes in pediatric patients undergoing ossicular chain reconstruction. *Int J Pediatr Otorhinolaryngol* **2017**, 99, 60-65.
63. McMullen, K.P.; Harris, M.S.; Dodson, E.E. Use of 2-Octyl cyanoacrylate in cartilage Interposition adherence during ossiculoplasty. *Laryngoscope* **2017**, 127, 731-734.
64. Mulazimoglu, S.; Saxby, A.; Schlegel, C.; Linder, T. Titanium incus interposition ossiculoplasty: audiological outcomes and extrusion rates. Eur Arch Otorhinolaryngol **2017**, 274, 3303-3310.
65. Choi, Y.S.; Shin, S.O. Results of hearing outcome according to the alloplastic ossicular prosthesis materials. *Indian J Otolaryngol Head Neck Surg* **2018**,70, 184-187.
66. Kahue, C.N.; O'Connnell, B.P.; Dedmon, M.M.; Haynes, D.S.; Rivas, A. Short and Long-Term Outcomes of Titanium Clip Ossiculoplasty. *Otol Neurotol* **2018**, 39, e453-e460.
67. Kong, J.; Jeong, C.; Shim, M.; Kim, W.; Yeo, S.; Park, S. Comparative study of new autologous material, bone-cartilage composite graft, for ossiculoplasty with Polycel® and Titanium. *Clin Otolaryngol* **2018**, 43, 434-439.
68. Kumar, S.; Yadav, K.; Ojha, T.; Sharma, A.; Singhal, A.; Gakhar, S. To evaluate and compare the result of ossiculoplasty using different types of graft materials and prosthesis in cases of ossicular discontinuity in chronic suppurative otitis media cases. *Indian J Otolaryngol Head Neck Surg* **2018**, 70, 15-21.
69. Lahlou, G.; Sonji, G.; De Seta, D.; Mosnier, I.; Russo, F.Y.; Sterkers, O.; Bernardeschi, D. Anatomical and functional results of ossiculoplasty using titanium prosthesis. *Acta Otorhinolaryngol Ital* **2018**, 38, 377-383.
70. Saliba I, Sabbah V, Poirier JB. Total ossicular replacement prosthesis: a new fat interposition technique. *Clin Med Insights Ear Nose Throat* **2018**, 11, 117955061774961.
71. Gu, F.M.; Chi, F.L. Titanium ossicular chain reconstruction in single stage canal wall down tympanoplasty for chronic otitis media with mucosa defect. *Am J Otolaryngol* **2019**, 40, 205-208.
72. Haidar, H; Abu Rajab Altamimi, Z.; Larem, A.; Aslam, W.; Elsaadi, A.; Abdulkarim, H.; Al Duhirat, E.; et al. The benefit of trans-attic endoscopic control of ossicular prosthesis after cholesteatoma surgery. *Laryngoscope* **2019**, 129, 2754-2759.
73. Wood, C.B., Yawn, R.; Lowery, A.S.; O'Connell, B.P.; Haynes, D.; Wanna, G.B. Long-term hearing outcomes following total ossicular reconstruction with titanium prostheses. *Otolaryngol Head Neck Surg* **2019**, 161, 123-129.
74. Mantsopoulos, K.; Thimsen. V.; Taha, L.; Eisenhut, F.; Müller, S.K.; Sievert, M.; Iro, H.; Hornung, J. Comparative analysis of titanium clip prostheses for partial ossiculoplasty. *Am J Otolaryngol* **2021**, 42, 103062.
75. Baazil AHA, Ebbens FA, Van Spronsen E, De Wolf MJF, Dikkers FG. Comparison of long-term microscopic and endoscopic audiologic results after total ossicular replacement prosthesis surgery. *Otol Neurotol* **2022**, 43, 1189-1195.
76. Bahmad F, Perdigão AG. Titanium prostheses versus stapes columella type 3 tympanoplasty: a comparative prospective study. *Braz J Otorhinolaryngol* **2022**, 88, 562-569.
77. Kraus, E.M.; Russell, G.B.; Allen, S.J.; Pearson, S.A. Long-term hearing results of endoskeletal ossicular reconstruction in chronic ears using titanium prostheses having a helical coil: Part 1 - Kraus K-Helix Crown, incus to stapes. *Otol Neurotol* **2022**, 43, 1056-1064.
78. Park, S.; Lim, K.H.; Lim, S.J.; Park, D.H.; Rah, Y.C.; Choi, J. Functional outcomes of single-stage ossiculoplasty in chronic otitis media with or without cholesteatoma. *J Int Adv Otol* **2022**, 18, 415-419.
79. Plichta, L.; Dabkowska, A.; Wawszczyk-Frohlich, S.; Skarzynski, H.; Skarzynski, P.H. Titanium prostheses for treating posttraumatic ossicular chain disruption. *J Int Adv Otol* **2022**, 18, 411-414.
80. Van Hoolst, A.; Wuyts, F.L.; Forton, G.E.J. Total ossicular chain reconstruction using a titanium prosthesis: functional results. *Eur Arch Otorhinolaryngol* **2022,** 279, 5615-5621.
81. Chien, C.; Tai, S.; Chan, L.P.; Wang, H.M.; Chang, N.C.; Wang, L.F.; Ho, K.Y.; Li, K.H. Predictive factors and audiometric outcome comparison between titanium prosthesis and autologous incus in traumatic ossicular injury. *Ann Otol Rhinol Laryngol* **2023**, 34894231181746. Epub ahead of print.
82. Faramarzi, M.; Roosta, S.; Faramarzi, A.; Kherad, M. Comparison of partial vs. total ossicular chain reconstruction using titanium prosthesis: a retrospective cohort study. *Eur Arch Otorhinolaryngol* **2023**, 280, 3567-3575.
83. Gülşen S, Çıkrıkcı S. A novel technique in treatment of advanced tympanosclerosis: results of malleus replacement and loop prostheses combination; pure endoscopic transcanal approach. *Eur Arch Otorhinolaryngol* **2023**, 280, 3601-3608.
84. Kálmán, J.; Horváth, T.; Dános, K.; Tamás, L.; Polony, G. Primary ossiculoplasties provide better hearing results than revisions: a retrospective cohort study. *Eur Arch Otorhinolaryngol* **2023**, 280, 3177-3185.

85. Kim, H.; Ha, J.; Choo, O.S.; Park, H.; Choung, Y.H. Which is better for ossiculoplasty following tympanomastoidectomy: Polycel® or Titanium? *Ann Otol Rhinol Laryngol* **2023**, 23, 34894231159969. Epub ahead of print.
86. Castiglione, A.; Benatti, A.; Velardita, C.; Favaro, D.; Padoan, E.; Severi, D.; Pagliaro, M.; et al. Aging, cognitive decline and hearing loss: effects of auditory rehabilitation and training with hearing aids and cochlear implants on cognitive function and depression among older adults. *Audiol Neurootol* **2016**, 21 Suppl 1, 21-28.
87. Bönitz, H.; Lunner, T.; Finke, M.; Fiedler, L.; Lyxell, B.; Riis, S.K.; Ng, E.; et al. How do we allocate our resources when listening and memorizing speech in noise? A pupillometry study. *Ear Hear* **2021**, 42, 846-859.
88. Martin, A.D.; Driscoll, C.L.W.; Wood, C.P.; Felmlee, J.P. Safety evaluation of titanium middle ear prostheses at 3.0 tesla. *Otolaryngol Head Neck Surg* **2005**, 132, 537-542.
89. Danti, S.; Stefanini, C.; D'Alessandro, D.; Moscato, S.; Pietrabissa, A.; Petrini, M.; Berrettini, S. Novel biological/biohybrid prostheses for the ossicular chain: fabrication feasibility and preliminary functional characterization. *Biomed Microdevices* **2009**, *11*, 783–793.
90. Sanna, M.; Hiroshi, S.; Mancini, F.; Russo, A.; Taibah, A.; Falcioni, M. Middle ear and mastoid microsurgery; Thieme: Stuttgart, Germany, 2018; pp. 187-244.