Review paper

The evolving landscape of head and neck brachytherapy: A scoping review

Marjorie Mae Cua, MD[1,2], Carl Jay Jainar, MD[3], Janella Ann Javenrie Calapit, MD[2], Michael Benedict Mejia, MD[3], Warren Bacorro, MD[1,3,4]

[1]Department of Radiation Oncology, Manila Doctors Hospital, Manila, Philippines, [2]Department of Radiation Oncology, Cardinal Santos Medical Center, San Juan, Philippines, [3]Department of Radiation Oncology, University of Santo Tomas Hospital – Benavides Cancer Institute, Manila, Philippines, [4]Department of Clinical Epidemiology, University of Santo Tomas – Faculty of Medicine and Surgery, Manila, Philippines

Abstract

Purpose: Since the last update of GEC-ESTRO (Groupe Européen de Curiethérapie – European Society for Therapeutic Radiology and Oncology) recommendations for head and neck (HN) brachytherapy in 2017, advances in understanding and management of HN cancers have influenced brachytherapy. We conducted a scoping review to depict the evolution of HN brachytherapy research and practice, and identify emerging topics since the previously published guidelines.

Material and methods: Systematic literature search was performed in PubMed, EBSCOhost, Europe PMC, and Google Scholar databases for articles on HN brachytherapy from 2017 onwards; the search was last done on June 29, 2023. We included primary studies on HN brachytherapy in English, complemented by bibliography scanning of secondary studies. Iterative team approach was employed in data extraction and charting. Quantitative and qualitative analyses and narrative synthesis were performed.

Results: Systematic search yielded 215 unique articles. A total of 132 primary studies were included: 112 on clinical outcomes (retrospective cohorts in majority, n = 72), and 22 were simulation and dosimetric studies. China consistently produced the most research output per year. The most studied sites were the oral cavity (n = 84), oropharynx (n = 37), and salivary glands (n = 20). While most reported on high-dose-rate brachytherapy (n = 57), there was resurgence of studies on low-dose-rate (LDR) brachytherapy (n = 50) in the form of permanent seed implants. In the latter, CT (n = 50) and template (n = 27) guidance were described. While majority discussed definitive brachytherapy, 18 reported on perioperative brachytherapy. Several reported on 3D printing for template and applicator design (n = 11) as well as new approaches to dose calculation or dose optimization algorithms (n = 2).

Conclusions: The current scoping review identified recent trends in HN brachytherapy, such as application in other HN sites, use of LDR seed implants, perioperative brachytherapy, and 3D printing in template design. Data from these recent publications provide a foundation for further investigations, which can generate evidence for succeeding guidelines.

J Contemp Brachytherapy 2024; 16, 3: 1–7
DOI: https://doi.org/10.5114/jcb.2024.140348

Key words: brachytherapy, 3D printing, perioperative brachytherapy, permanent seed implant, head and neck cancers.

Purpose

In 2017, the GEC-ESTRO (Groupe Européen de Curiethérapie – European Society for Therapeutic Radiology and Oncology) published an update of its recommendations for head and neck (HN) brachytherapy. This update focused on the implementation of cross-sectional imaging-based treatment and stepping source technology. The guidelines addressed various topics, such as dose and fractionation, selection of brachytherapy for different treatment indications, quality assurance, and physical aspects [1].

Since its publication, advances in the understanding and management of head and neck cancers have influenced the practice of brachytherapy [2, 3]. The present scoping review aimed to depict the evolution of HN brachytherapy research and practice as reflected in published literature from 2017 to 2023, and to identify emerging topics since the previously published recommendations.

Material and methods

Our methodology and results were reported according to the preferred reporting items for systematic re-

Address for correspondence: Marjorie Mae Cua, MD, Department of Radiation Oncology, Manila Doctors Hospital, Manila, Philippines, phone: +63-9177035980, ✉ e-mail: marjoriecua@gmail.com

Received: 27.12.2023
Accepted: 03.05.2024
Published:

views and meta-analyses extension for scoping reviews (PRISMA-ScR) [4].

Systematic search

A systematic literature search was performed in PubMed, EBSCOhost, Europe PMC, and Google Scholar databases for articles on HN brachytherapy. Search strategies included the following: "SU brachytherapy AND SU (head and neck cancer)" for EBSCOhost, "(brachytherapy-[MeSH Major Topic]) AND (head and neck cancer[MeSH Major Topic])" for PubMed, "(KW:"brachytherapy" AND KW:"head and neck cancer")" for Europe PMC, and "allintitle: brachytherapy AND "head and neck" OR nasopharynx OR nose OR nas OR oropharynx OR oral OR orbit OR lip OR buccal OR tongue OR lingual OR neck OR sinus OR sino OR maxilla" for Google Scholar. A filter was applied for articles published from the year 2017 onwards. The last search was done on June 29, 2023.

Study selection

Clinical trials, prospective and retrospective cohort studies, cross-sectional studies, case series, case reports, and dosimetric and simulation studies were included. Dosimetric studies were those reporting on doses from treatment plans that were actually delivered to patients; simulation studies were those that used image datasets from brachytherapy cases or phantoms, and reported on simulated doses based on hypothetical dose regimens that were not delivered to patients. Letters, editorials, and commentaries were excluded. Bibliographies of guidelines and systematic reviews were scanned for other relevant titles. Only studies in English were included. Each study was screened by one of four reviewers, and checked by a second. Any disagreement was resolved by discussion with other reviewers (Figure 1).

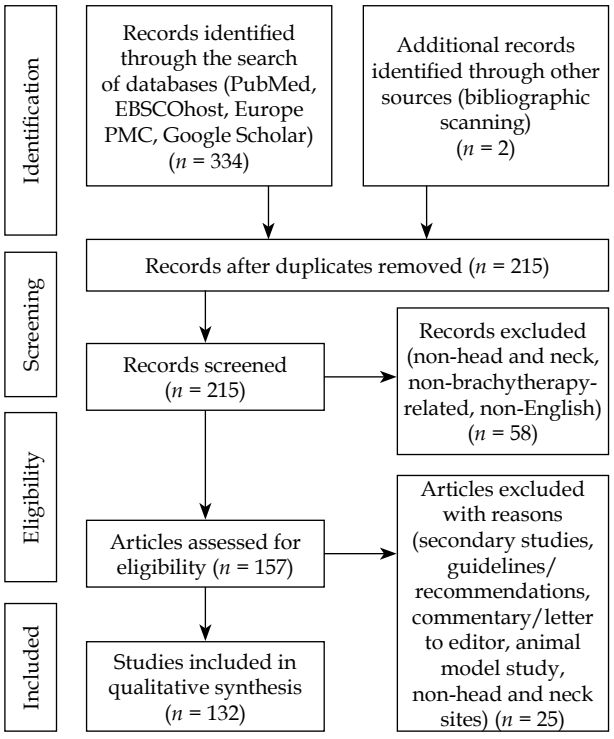

Fig. 1. PRISMA diagram of the articles screened and included in the review

Data extraction and charting

Four reviewers performed data extraction. The final list of screened articles was equally divided between two sets of independent reviewers, with each pair working on a designated subset. In case of a conflict or discrepancy, a third reviewer would arbitrate.

Study details were extracted from articles using a standardized template. An iterative team approach to data charting (categorization, extent of detail) was employed, beginning with five pilot charts for each reviewer. In the last iteration, the following data were tabulated: HN subsite, other topics discussed (e.g., re-irradiation, nursing, physics, training), publication year, treatment period (if applicable), origin of publication, study design, number of patients, dose-rate (i.e., LDR, pulsed-dose-rate [PDR], high-dose-rate [HDR]), implant technique (i.e., intracavitary, interstitial, mold, combined), implant approach (i.e., free-hand, template-guided), implant guidance (i.e., visual-guided, palpation-guided, imaging-guided), treatment setting (i.e., definitive, post-operative, perioperative), method details reported, outcomes reported, and analyses performed. Given the objective, no formal risk of bias appraisal was done [5].

Data analysis

Quantitative analysis was completed with descriptive frequency counts of the tabulated entries for each category of extracted information. Qualitative content analysis was performed using a method described by Hancock [6]. A narrative synthesis on the identified emerging themes was formulated and discussed in the context of topics in the GEC-ESTRO 2017 recommendations.

Results

This systematic search and bibliographic scanning yielded 215 unique articles, including one guideline and six systematic reviews. A total of 132 primary studies from 2017 to 2023 were included.

Temporal and geographical trends

In this period, there was no noticeable upward or downward trend in the number of publications on HN brachytherapy, with an average of 21 publications per year from 2017 to 2022. More than two-thirds of the publications came from China, the United States of America (USA), India, and Japan (Table 1). China consistently produced the most research output per year from 2017 to 2022. Since 2020, an increasing proportion of published studies originated from Japan.

Study types

A total of 112 studies reported clinical outcomes, including four clinical trials, 17 prospective cohorts, 72 ret-

Table 1. Publications per country

Country	Number of studies
China	39
United States of America	24
India	16
Japan	17
France, Hungary, Italy	4
Canada, Spain	3
Israel, Netherlands, Philippines, Poland, Russia, South Korea	2
Australia, Czechia, Finland, Germany, Iran, Morocco, Sweden, Switzerland, Taiwan	1

rospective cohorts, four case series, and 15 case reports. Of these, 89 studies reported outcomes of cohorts treated in the 2000s and 2010s. The largest number of patients included in a single report was a retrospective cohort from the USA, with brachytherapy outcomes for base of tongue carcinoma using national registry data of 15,934 patients treated from 2004 to 2012 [7]. A total of 22 articles included simulation (n = 11), dosimetric (n = 7), and physics (n = 4) studies.

Clinical studies

Among clinical research, the most studied sites were the oral cavity (n = 84), oropharynx (n = 37), and salivary glands (n = 20). The subsites studied are detailed in Table 2. Furthermore, 21 studies investigated re-irradiation using brachytherapy, 5 pediatric brachytherapy, and 10 combination with other modalities, such as external beam irradiation, chemotherapy, chemoradiation, or pre-operative trans-arterial chemoembolization.

Where dose-rate was specified, HDR (n = 57) or LDR (n = 50) brachytherapy were predominantly investigated. Four studies reported PDR brachytherapy, and six a combination of two or all the above. Most LDR studies explored permanent seed implants (PSI) using ^{125}I (n = 39). Majority of HDR or PDR studies used ^{192}Ir (n = 34). Others reported the use of ^{198}Au (n = 8), ^{131}Cs (n = 5), ^{60}Co (n = 2), ^{103}Pd (n = 4), ^{252}Cf (n = 1), and ^{224}Ra (n = 2).

The treatment setting as well as implant technique, approach, and guidance described in the studies are summarized in Table 3. Brachytherapy was applied in definitive, post-operative, or perioperative settings in 78, 33, and 17 studies, respectively. Interstitial, mold, and intra-cavitary techniques were described in 105, 13, and 5 studies respectively. Five studies also utilized a combination of these techniques. Free-hand approach was used in 88 studies, and template-based approach in 27. Nearly all studies used image-guided methods (n = 52), mostly PSI studies. Of these, 50 were CT-guided and 2 ultrasound-guided. Other studies described visual (n = 57) or palpation (n = 25) guidance.

Pre-clinical studies

Among pre-clinical studies, 11 discussed 3D-printing and 6 reported applicator design. Two physics papers dis-

Table 2. Sites and subsites studied

Site/subsite	Number of studies
Head and neck (mixed)	25
Oral cavity	84
Oral tongue	27
Lip	14
Floor of the mouth	11
Buccal mucosa	9
Hard palate	2
Gingiva or alveolar ridge	4
Retromolar trigone	2
Mixed	15
Oropharynx	37
Base of the tongue	12
Soft palate	6
Tonsil	5
Vallecula	3
Mixed	11
Salivary gland	20
Parotid	16
Mixed	4
Paranasal sinuses	14
Maxillary	9
Ethmoid	1
Mixed	4
Nasopharynx	12
Skin and scalp	11
Skin	7
Scalp	1
Stoma	1
Parastomal	2
Neck node metastases	9
Nasal cavity	4
General	2
Nasal vestibule	2
Ocular	7
Orbit	5
Eyelid	2
Larynx	7
Hypopharynx	6
Ear and external auditory canal	3
Ear	2
External auditory canal	1
Others	13
Parapharyngeal space	5
Infratemporal fossa	3
Mandible	1
Meningeal surface	1
Pterygoid fossa	1

Table 3. Treatment setting, and implant technique, approach, and guidance

Setting	Number of studies
Definitive	78
Post-operative	33
Perioperative	17
Not specified	19
Implant technique	
Interstitial	105
Intra-cavitary	5
Mold	13
Combined	2
Not specified	13
Implant approach	
Free-hand	88
Template-guided	27
Combined	3
Not specified	23
Implant guidance	
CT-guided	50
US-guided	2
Visual-guided	57
Palpation-guided	25
Not specified	23

cussed new approaches to dose calculation and dose optimization algorithms. Two studies investigated the use of novel radioactive sources, such as ^{252}Cf (n = 1), ^{75}Se (n = 1), ^{169}Yb (n = 1), and ^{153}Gd (n = 1). Other pre-clinical studies explored ^{198}Au (n = 1), ^{131}Cs (n = 2), and ^{60}Co (n = 1).

Discussion

This scoping review investigated emerging themes in HN brachytherapy publications in the last seven years, which were identified from the frequency counts of the extracted data. We now discuss these emerging themes in relation to the existing recommendations from the GEC-ESTRO [1]. Table 4 summarizes the main points of the discussion.

Low-dose-rate permanent seed brachytherapy

The latest update of the 2017 GEC-ESTRO recommendations discussed general aspects of treatment planning, including target volume definition, treatment planning parameters with current stepping source systems, and fractionation schedules for HDR and PDR brachytherapy [1]. Recent publications suggest a resurging interest in LDR brachytherapy, particularly in the form of PSI, as shown by the growing number of studies on this technique (n = 50). It was applied in the definitive or post-operative treatment of locally advanced or inoperable cancers [8-10], early tongue cancers [11], parotid malignancies [12-17], and minor salivary gland carcinomas of the lip and buccal mucosa [18]. Details on the methods of implantation, dosimetric planning, and treatment delivery are described in these studies. Iodine-125 seeds were mostly used, with prescribed doses ranging from 60 Gy to 160 Gy in the mentioned articles. Various reports also described the utility of LDR seed brachytherapy in the setting of re-irradiation or recurrent tumors. Doses applied in these studies ranged from 90 Gy to 160 Gy using ^{125}I seeds [19-24], and from 40 Gy to 70 Gy using ^{131}Cs seeds [25-27]. To our knowledge, there are no current specific guidelines for this modality. Further analysis of data from methodologies and outcomes of these studies may provide evidence for future recommendations on implantation, dosimetry, and treatment planning.

Subsites

The GEC-ESTRO guidelines included discussions regarding the role of primary brachytherapy in malignancies, such as lip, oral cavity, oropharynx, nasopharyngeal, and superficial cancers [1].

Several retrospective studies in this review reported the application of brachytherapy in salivary gland malignancies, particularly parotid cancers. As mentioned previously, several studies on LDR PSIs were performed on

Table 4. Emerging topics in relation to areas addressed in the 2017 GEC-ESTRO recommendations

Topic	GEC-ESTRO recommendations (2017 update) [1]	Emerging interests (2017-2023)
Fractionation schedules	Schedules for HDR and PDR brachytherapy (transitioning from LDR wires)	Increasing literature on LDR permanent seed implant may provide evidence for recommendations on dosimetry and treatment planning
Brachytherapy use in specific subsites	Discussed primary brachytherapy in lip, oral cavity, oropharynx, nasopharynx, and superficial cancers	Emerging data on the utilization of interstitial seed brachytherapy for parotid cancers
Adjuvant brachytherapy	Predominantly delivered post-operatively, with intra-operative and pre-operative brachytherapy considered investigational	Increasing literature on the use of perioperative brachytherapy, with one study reporting longer follow-up (10-year recurrence and survival rates)
Physics	Reported on implant checking, treatment planning, dose calculation, and treatment delivery	Initial data from simulated plans generated from inverse planning algorithms, and on the performance of a model-based dose calculation algorithm
3D printing	Not discussed	Several articles discussing 3D printing for template and applicator design

HDR – high-dose-rate, PDR – pulsed-dose-rate, LDR – low-dose-rate

this site, and patients were treated both in definitive and post-operative setting. There are articles reporting LDR as an effective primary treatment in the definitive setting without causing severe complications [12, 17]. These findings indicate that there may be emerging data on utilization of LDR seed brachytherapy for parotid cancers, which warrant further investigations.

Perioperative brachytherapy

In addition to discussion on brachytherapy as a primary modality of treatment, the 2017 GEC-ESTRO recommendations also tackled the role of adjuvant brachytherapy. Most of the discussion focused on the use of post-operative brachytherapy performed 1-2 months after surgery [1].

While post-operative brachytherapy remains the more common adjuvant procedure in recent literature (n = 33), studies on perioperative brachytherapy are also growing. With some publications reporting longer follow-up, these additional data can add to the current evidence on its oncologic outcomes and toxicity. For example, acceptable six-year loco-regional outcomes of its use in early mobile tongue cancer was reported [28]. Also, in Khan *et al*. study, ten-year data on recurrences and overall survival rates were described on its application in the salvage setting for neck recurrences, showing encouraging results and relatively low toxicity rates [29].

Salvage brachytherapy and re-irradiation

The 2017 recommendations recognized salvage brachytherapy as a treatment option in previously irradiated patients. A continued interest in salvage brachytherapy in the setting of re-irradiation was seen, as more studies in recent years (n = 21) further investigated its role. Procedures employed different techniques using HDR, PDR, or LDR brachytherapy, and were performed in different HN sites. In addition to several case reports and retrospective studies, recent prospective data were delivered on this topic. In a study by Martínez-Fernández *et al*. on 63 patients, perioperative HDR brachytherapy in addition to surgery resulted in long-term loco-regional control, with a 5-year loco-regional control rate of 55% [30]. However, the authors observed significant rates of toxicities, with 50.8% of patients experiencing at least grade 3 adverse effects. Luginbuhl *et al*. enrolled 49 patients in a prospective study using intra-operative ^{131}Cs seed brachytherapy. They demonstrated comparable outcomes in comparison with historical cohorts and acceptable safety profile. Two-year disease-free survival was reported in 49%, and rates of osteo-radionecrosis and percutaneous endoscopic gastrostomy (PEG) tube placement were low [26].

Physics

The discussion on general quality assurance and physical aspects in the 2017 GEC-ESTRO recommendations described practical guidance on the procedure of implant checking, treatment planning, dose calculation, and treatment delivery. Recent studies on the physical aspect of brachytherapy included some dosimetric or simulation research. One study compared the dosimetric results, total dwell time, and number of active positions between plans generated by inverse planning simulated annealing (IPSA) and hybrid inverse planning and optimization (HIPO). They observed comparable dosimetric results between the two algorithms, and a benefit of shorter dwell time using HIPO [31]. Another study determined the performance of advanced collapsed-cone engine (a model-based dose calculation algorithm) in treatment planning for scalp brachytherapy. This was compared with the Task Group 43 (TG-43) dose calculations, in which similar doses were found above the skull layer of the phantom, while an underestimation of the dose through the bone was observed [32].

Applicator design and 3D printing

Applicator design and 3D printing were also among the major themes in simulation studies found in the current review [21, 33-36]. These studies described in detail the process of applicator design and fabrication. No specific recommendations have been provided on this topic yet, but emerging interest in this practice may deliver insights on its value.

For general HN cancer sites, brachytherapy using collagen matrix tiles with ^{131}Cs was investigated in a cadaveric study, and reported feasibility, ease of use, and less carotid dose [33]. For nasopharyngeal cancers, a novel applicator design for intra-cavitary brachytherapy was proposed. A simulation study compared the dosimetric outcomes with the Rotterdam nasopharyngeal applicator, and demonstrated significantly lower soft palate doses with the new design [34].

Various studies also investigated the application of 3D printing in the fabrication of templates and applicator guides. A 3D-printed patient-specific applicator guide for oral tongue cancers was used in a phantom study. Insertion time, geometric accuracy, and dose-volumetric analysis were reported, showing improvement in the treatment process, catheter positioning, and dose homogeneity [35]. There were also retrospective studies on 3D-printed templates in patients who underwent ^{125}I seed brachytherapy for recurrent tumors [21, 36]. The utilization of 3D-printed templates resulted in improvements in dosimetry and positioning, with no obvious adverse reactions. Similarly, 3D-printed templates were used for seed implant brachytherapy in cervical node metastases, and resulted in accurate positioning without complications [37].

Another study on personalized brachytherapy involved the use of a 3D-printed anthropometric phantom and lead shielding for the eyes in facial surface brachytherapy procedures. The study aimed to verify the doses to critical organs by measuring the calculated and measured doses, and reported using lead shield as a method for protection of organs at risk [38].

Limitations

This study has limitations inherent to the nature of scoping reviews. We aimed to include a large comprehen-

sive body of literature to determine recent trends in HN brachytherapy research. Due to its broad scope, the depth of analysis of outcomes was limited, and critical appraisal was not done on each of the included studies to assess the quality of evidence. Generating evidence, as a basis for standard clinical practice, was beyond the scope of this review. However, the emerging topics identified in this study may direct further investigations, systematic reviews, or meta-analyses, which can serve as basis for future recommendations. Moreover, relevant studies may have been missed due to the exclusion of non-English publications, especially considering the abundance of HN brachytherapy studies coming from regions where English is not the primary language.

Conclusions

In summary, this scoping review identified recent trends in HN brachytherapy, such as the use of LDR seed implants, its application in other HN sites, perioperative brachytherapy, and 3D printing in template design. Data from these recent publications can provide a foundation for further reviews and investigations, which can generate evidence for succeeding guidelines in HN brachytherapy.

Funding

This research received no external funding.

Disclosures

Approval of the Bioethics Committee was not required.

The authors report no conflict of interest.

References

1. Kovács G, Martinez-Monge R, Budrukkar A et al. GEC-ESTRO ACROP recommendations for head & neck brachytherapy in squamous cell carcinomas: 1st update – Improvement by cross sectional imaging based treatment planning and stepping source technology. *Radiother Oncol* 2017; 122: 248-254.
2. Li Y, Jiang Y, Qiu B et al. Current radiotherapy for recurrent head and neck cancer in the modern era: a state-of-the-art review. *J Transl Med* 2022; 20: 566.
3. Budrukkar A, Guinot JL, Tagliaferri L et al. Function preservation in head and neck cancers. *Clin Oncol (R Coll Radiol)* 2023; 35: 497-506.
4. Tricco AC, Lillie E, Zarin W et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and explanation. *Ann Intern Med* 2018; 169: 467-473.
5. Khalil H, Peters MD, Tricco AC et al. Conducting high quality scoping reviews-challenges and solutions. *J Clin Epidemiol* 2021; 130: 156-160.
6. Hancock B. Trent focus for research and development in primary health care: An introduction to qualitative research. Trent Focus, Nottingham 1998: 1-24.
7. Lee A, Givi B, Wu SP et al. Patterns of care and impact of brachytherapy boost utilization for squamous cell carcinoma of the base of tongue in a large, national cohort. *Brachytherapy* 2017; 16: 1205-1212.
8. Zhang M, Zhang J, Hu B et al. The efficacy and safety of 125I brachytherapy combined with pre-operative transarterial chemoembolization in patients with locally advanced head and neck cancer. *Front Oncol* 2022; 12: 992399.
9. Zhao G, Wang Z, Li C et al. A retrospective study on unresectable or inoperable head and neck cancers treated with stereotactic ablative brachytherapy. *J Contemp Brachytherapy* 2022; 14: 519-526.
10. Zhong YW, Lyu XM, Shi Y et al. Long-term result of 125 I seed brachytherapy for pediatric desmoid tumor in the head and neck. *Pediatr Blood Cancer* 2023; 70: e30037.
11. Konishi M, Fujita M, Takeuchi Y et al. Treatment outcomes of real-time intraoral sonography-guided implantation technique of 198Au grain brachytherapy for T1 and T2 tongue cancer. *J Radiat Res (Tokyo)* 2021; 62: 871-876.
12. Huang MW, Wu WJ, Lv XM et al. The role of 125I interstitial brachytherapy for inoperable parotid gland carcinoma. *Brachytherapy* 2018; 17: 244-249.
13. Li J, Zhang J, Lyu XM et al. Efficacy of surgery combined with postoperative 125 I interstitial brachytherapy for treatment of acinic cell carcinoma of the parotid gland in children and adolescents. *Pediatr Blood Cancer* 2020; 67: e28343.
14. Ma YQ, Zheng L, Huang MW et al. Surgery combined with 125I brachytherapy for treatment of carcinoma ex pleomorphic adenoma of the parotid gland. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2021; 131: 395-404.
15. Mao MH, Zheng L, Wang XM et al. Surgery combined with postoperative 125I seed brachytherapy for the treatment of mucoepidermoid carcinoma of the parotid gland in pediatric patients. *Pediatr Blood Cancer* 2017; 64: 57-63.
16. Wu ZY, Wu WJ, Zheng L et al. Efficacy of combined surgery and 125I seed brachytherapy for treatment of primary mucoepidermoid carcinoma of the parotid gland. *Head Neck* 2019; 41: 3219-3225.
17. Zhou C, Zhang J, Zhang JG et al. Iodine-125 brachytherapy alone for advanced primary parotid gland carcinoma. *Int J Oral Maxillofac Surg* 2018; 47: 561-567.
18. Wu WJ, Shao X, Huang MW et al. Postoperative iodine-125 interstitial brachytherapy for the early stages of minor salivary gland carcinomas of the lip and buccal mucosa with positive or close margins. *Head Neck* 2017; 39: 572-577.
19. Breen W, Kelly J, Park HS et al. Permanent interstitial brachytherapy for previously irradiated head and neck cancer. *Cureus* 2018; 10: e2517.
20. Chen Y, Jiang Y, Ji Z et al. Efficacy and safety of CT-guided 125I seed implantation as a salvage treatment for locally recurrent head and neck soft tissue sarcoma after surgery and external beam radiotherapy: A 12-year study at a single institution. *Brachytherapy* 2020; 19: 81-89.
21. Jiang Y, Ji Z, Guo F et al. Side effects of CT-guided implantation of 125I seeds for recurrent malignant tumors of the head and neck assisted by 3D printing non co-planar template. *Radiat Oncol* 2018; 13: 18.
22. Jiang P, Wang J, Ran W et al. Five-year outcome of ultrasound-guided interstitial permanent 125I seeds implantation for local head and neck recurrent tumors: a single center retrospective study. *J Contemp Brachytherapy* 2019; 11: 28-34.
23. Jiang Y, Zhen P, Dai J et al. Long-term safety and efficacy of CT-guided I125 radioactive seed implantation as a salvage therapy for recurrent head and neck squamous carcinoma: A multicenter retrospective study. *Front Oncol* 2021; 11: 645077.
24. Li Y, Jiang Y, Wang J. Safety and efficacy of CT-guided radioactive iodine-125 seed implantation as a salvage treatment for recurrent head and neck cancer after two or more courses of radiotherapy. *Radiat Oncol* 2023; 18: 73.
25. Kharouta M, Zender C, Podder T et al. Permanent interstitial cesium-131 brachytherapy in treating high-risk recurrent head and neck cancer: A prospective pilot study. *Front Oncol* 2021; 11: 639480.

26. Luginbuhl A, Calder A, Kutler D et al. Multi-institutional study validates safety of intraoperative cesium-131 brachytherapy for treatment of recurrent head and neck cancer. *Front Oncol* 2021; 11: 786216.
27. Walsh A, Hubley E, Doyle L et al. Carotid dosimetry after re-irradiation with 131Cs permanent implant brachytherapy in recurrent, resected head and neck cancer. *J Contemp Brachytherapy* 2019; 11: 221-226.
28. Potharaju M, Raj HE, Muthukumaran M et al. Long-term outcome of high-dose-rate brachytherapy and perioperative brachytherapy in early mobile tongue cancer. *J Contemp Brachytherapy* 2018; 10: 64-72.
29. Khan N, Clemens M, Liu J et al. The role of salvage surgery with interstitial brachytherapy for the management of regionally recurrent head and neck cancers. *Cancers Head Neck* 2019; 4: 4.
30. Martínez-Fernández MI, Alcalde J, Cambeiro M et al. Perioperative high dose rate brachytherapy (PHDRB) in previously irradiated head and neck cancer: Results of a phase I/II reirradiation study. *Radiother Oncol J Eur Soc Ther Radiol Oncol* 2017; 122: 255-259.
31. Choi CH, Park SY, Park JM et al. Comparison of the IPSA and HIPO algorithms for interstitial tongue high-dose-rate brachytherapy. *PLoS One* 2018; 13: e0205229.
32. Cawston-Grant B, Morrison H, Sloboda RS et al. Experimental assessment of the Advanced Collapsed-cone Engine for scalp brachytherapy treatments. *Brachytherapy* 2018; 17: 489-499.
33. Agarwal A, Pinto J, Renslo B et al. Feasibility of collagen matrix tiles with cesium-131 brachytherapy for use in the treatment of head and neck cancer. *Brachytherapy* 2023; 22: 120-124.
34. Bacorro WR, Agas RAF, Cabrera SMR et al. A novel applicator design for intracavitary brachytherapy of the nasopharynx: Simulated reconstruction, image-guided adaptive brachytherapy planning, and dosimetry. *Brachytherapy* 2018; 17: 709-717.
35. Choi CH, Kim JI, Park JM. A 3D-printed patient-specific applicator guide for use in high-dose-rate interstitial brachytherapy for tongue cancer: A phantom study. *Phys Med Biol* 2019; 64: 135002.
36. Qiu B, Jiang Y, Ji Z et al. The accuracy of individualized 3D-printing template-assisted I125 radioactive seed implantation for recurrent/metastatic head and neck cancer. *Front Oncol* 2021; 11: 664996.
37. Liang Y, Wang Z, Zhang H et al. Three-dimensional-printed individual template-guided 125I seed implantation for the cervical lymph node metastasis: A dosimetric and security study. *J Cancer Res Ther* 2018; 14: 30-35.
38. Zwierzchowski G, Bielęda G, Szymbor A et al. Personalized superficial HDR brachytherapy-dosimetric verification of dose distribution with lead shielding of critical organs in the head and neck region. *J Pers Med* 2022; 12: 1432.