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ORIGINAL ARTICLE

Systematic review of ablation techniques for the treatment of malignant or aggressive benign lesions in children

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Abstract
Background Ablation techniques are widely used for solid malignant tumors in adults. There is no large series assessing the effectiveness of local ablative therapies in the treatment of malignant or aggressive benign lesions in children.
Objective To review the existing evidence on the techniques and results of ablation for pediatric solid malignant or aggressive benign tumors.
Materials and methods We searched MEDLINE for papers published between 1995 and 2012 that reported outcomes of radiofrequency, microwave and cryoablation, interstitial laser therapy, irreversible electroporation and percutaneous ethanol injection for patients younger than 18 years old. Data collection included factors related to the patient, tumor biology, ablation technique and cancer-specific endpoints. Additional series of predominantly adults including data on patients younger than 18 years old were also identified.
Results We identified 28 patients treated by ablation in 29 regions: 5 patients undergoing ablation for liver lesions, 9 patients for lung metastases, 11 patients for bone and/or soft tissue and 4 patients for kidney or pancreas. The ablation was performed to treat primary tumors, local recurrences and metastases. The histology of the tumors was osteosarcoma in 6 patients, Wilms tumor in 3, rhabdomyosarcoma in 3, hepatoblastoma in 3, desmoid tumor in 3, adrenocortical carcinoma in 2 and a single case each of leiomyosarcoma, Ewing sarcoma, paraganglioma, solid-pseudopapillary neoplasm, sacrococcygeal teratoma, hepatic adenoma, juxtaglomerular cell tumor and plantar fibromatosis. Eighteen of the patients (64%) experienced a complication, but only 6 (21%) of these needed treatment other than supportive care.
Conclusions Although ablative techniques are feasible and promising treatments for certain pediatric tumors, large multicenter prospective trials will be needed to establish efficacy.

Keywords Percutaneous ablation · Neoplasms · Children · Systematic review

Introduction

Local ablation techniques are widely used in adults for the treatment of both benign and malignant lesions [1–5]. They can be divided, depending on the mechanism they use to cause injury, into thermal therapies such as radiofrequency ablation, percutaneous cryoablation, microwave ablation and interstitial laser thermotherapy; chemical ablative techniques, typified by percutaneous ethanol injection, and irreversible electroporation, which alters the electrical conductivity and permeability of the cell membrane by means of high-voltage pulses, causing both cellular disruption and thermal damage [6]. In some cases, these techniques are included in the algorithms of treatment of oncological diseases at the same level as more aggressive techniques such as surgical resection [7], in others they represent an alternative to surgery in patients who are not candidates for resection due to high anesthetic risk or other circumstances [2, 3, 5]. These techniques may also have an impact on the immune system of patients by activating a tumor-associated antigen-specific T cell response [8–10]. Local ablation can be carried out with

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curative or palliative intent, either alone or in combination with systemic (immunotherapy or chemotherapy) [11] or locoregional therapies (radiotherapy or chemoembolization) [5, 12]. The effect of systemic chemotherapy may be enhanced by the physiological changes produced by thermal ablation [11]. Furthermore, ablation can sometimes be used as a complement to surgery, individualizing the treatment for each lesion in a single patient [13]. These treatments have been applied to tumors located in almost every organ in the human body including the liver, kidney, lung, musculoskeletal system and pancreas [1–13]. Although thermal ablation is widely regarded as the treatment of choice for osteoid osteoma in extraspinal locations [14] and thermal and chemical ablation techniques have been used for thyroid or benign vascular tumors, among others [15, 16], the use of these techniques still remains exceptional in children with malignancy. In this systematic review we aim to report the techniques and results of ablation for solid malignant or borderline tumors in children.

Materials and methods

We limited the search start to 1995, as the application of these techniques was infrequent even in adults before then. No language restriction was applied. We followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement (http://www.prisma-statement.org/statement.htm). We performed a search in MEDLINE including the terms: (radiofrequency) OR (microwave) OR (percutaneous ethanol) OR (interstitial laser) OR (irreversible electroporation) OR cryoablation NOT (osteoid osteoma) AND (malignan* OR tumor). For each paper we extracted: title, authors, year of publication, journal name, type and subtype of journal (medical, surgery, radiology or others and general or pediatrics), type of study, strength of evidence according to the Oxford Centre for Evidence-based Medicine, number of patients (including only those <18 years), mean of time to progression (time from inclusion to radiological progression), mean of time to recurrence (time from inclusion to recurrence), mean time of overall survival (time from inclusion to death) and mean lesion diameter or volume. For each individual patient we recorded: age, sex, body mass, type of tumor (histology), nature of diagnosis (primary or metastatic), size of tumor (diameter or volume), location, other treatment after ablation, ablation technique (radiofrequency ablation, microwave ablation, percutaneous cryoablation, percutaneous ethanol injection, irreversible electroporation, interstitial laser thermotherapy), electrode size, anesthesia type (general [GA], local with or without sedation), number of lesions, number of ablation sessions, guidance technique (US, MRI, CT, fluoroscopy), technical success (proper positioning of the ablation device into the target area with completion of the planned treatment), clinical success (accomplishing clinical goal of ablation), duration of hospitalization following ablation, overall survival, complications and status at the end of the study (died of disease - DOD, alive with evidence of disease – AWED, or no evidence of disease – NED). Abstracts were screened to identify the relevance of the retrieved reports. Further screening of cited references was undertaken to detect any studies that may have been missed from our initial search. Two reviewers independently extracted data from all studies onto a predefined data collection form. Any discrepancies were resolved by consensus among four of the authors (D.J.R, S.S., P.A.P, F.G.M). Due to the small number of studies reporting results of ablation in children, we aimed to include every case describing the use of the techniques stated above for malignant and locally aggressive tumors. We reviewed the resulting cases according to the target organ ablated (liver, lung, bone and/or soft tissues, and kidney or pancreas).

Results

Adding the exception of the Hoffer et al. paper [17], which is a phase I study, relevant data was missing for many of the reported cases. The age was reported in all cases. The mean age of the 28 patients identified was 9 years (range: 1 day to 17 years). The sex was reported in 18 patients (64%), 13 females and 5 males. Body mass was reported in only 5 of the 28 patients (18%), with a median of 16 kg (range: 13–41 kg). The histology of all tumors was reported: osteosarcoma in 6 patients (21%), Wilms tumor in 3 (11%), rhabdomyosarcoma in 3 (11%), hepatoblastoma in 3 (11%), desmoid tumor in 3 (11%), adrenocortical carcinoma in 2 (7%) and leiomyosarcoma, Ewing sarcoma, paraganglioma, solid-pseudopapillary neoplasm, sacrococcygeal teratoma, hepatic adenoma, juxtaglomerular cell tumor and plantar fibromatosis in 1 case each (3%). The nature of the lesion (primary, recurrent or metastatic) was reported in 28 of the 29 locations ablated (96%). Among the 29 locations treated, according to chronology, there were primary tumors in 11 cases (38%), local recurrence in 4 cases (14%) and metastases in 12 cases (42%). The diameter or volume of the ablated lesions was described in 26 of the 28 patients (92%). The paper describing the most patients [17] did not list the individual size of the 56 lesions treated, but reported a range from 0.13 ml to 750 ml (median: 7 ml; mean: 46 ml). In the 14 remaining patients the diameter ranged from 8 mm to 170 mm (median: 18 mm; mean:

45 mm). We identified 28 patients treated by means of ablation in 29 regions (one of the patients underwent both lung and bone radiofrequency ablation). Five patients underwent liver ablation (18%), 9 patients lung ablation (32%), 11 patients bone and/or soft-tissue ablation (39%) and 4 patients underwent kidney or pancreas ablation (14%). After the 29 ablations, the need for additional treatment was explained in 28 cases (97%): In 14 cases (50%) the patients did not need further treatment and in 16 cases systemic chemotherapy alone or together with surgery, surgery alone or together with embolization, or radiotherapy (conventional or brachytherapy) were used. The technique was radiofrequency ablation in 26 cases (90%), percutaneous cryoablation in 2 (7%) and percutaneous ethanol injection in 1 (3%). Excluding the patient treated by means of percutaneous ethanol injection, the type of cryoprobe or electrode needle and size was reported in 15 cases (54%). The anesthetic technique was GA in 28 cases (97%) and local anesthetic with sedation in 1 (3%). The total number of ablated lesions was 65 (median: 2) in 92 ablation sessions (median: 3). In Hoffer's [17] series the median hospital stay was 3 days (range: 2-25 days). Survival was reported for 26 of the 28 patients (93%), with mean overall survival of 22 months (median: 18 months; range: 0.7-96 months).

Bone and soft-tissue ablations (Table 1)

We identified 11 patients who underwent bone and soft-tissue ablation in six papers [17–22]. The mean and median age of the patients was 10 years. Four were female and two male, and in five patients the sex was not reported. The weight was only reported in one patient, who weighed 41 kg. The histology of the tumors was rhabdomyosarcoma in three patients, desmoid tumor in two and leiomyosarcoma, paraganglioma, osteosarcoma, Ewing sarcoma, plantar fibromatosis and teratoma in one each. The location of the ablation was soft tissue in six patients (presacral, breast, tensor fascia lata, lumbar muscles, oral cavity and plantar fascia) and bone in five (maxilla, radius, femur, ribs and sacrum). In four cases, the tumors were primary; in two local recurrences, in two metastases and for three patients the nature of the lesion was not reported. The mean of the reported diameters of the ablated lesions was 70 mm, and in six cases the size was not reported. A total of 17 lesions were ablated in 32 sessions. Four patients received additional systemic therapy (chemotherapy in three and antiviral therapy in one), one with additional embolization. Two patients were treated with additional regional therapy (embolization and radiotherapy) without systemic therapy. Except for four patients (one percutaneous cryoablation and three radiofrequency ablation), the type of needle used in the procedure was not reported. All of the treatments were performed under GA and except for one patient (with Ewing sarcoma undergoing percutaneous cryoablation) the ablative technique used was radiofrequency ablation. In six cases, the guidance technique was CT; in four, CT and US were combined, and in one case, US was the only modality used. Technical success was achieved in nine cases. Clinical success was obtained in eight patients. The outcome was unreported in one. The duration of post-ablation hospitalization was only specified in two cases (both less than 1 day). Mean overall survival of the patients for whom this data was reported was 15 months (median: 12 months). Eight patients suffered a complication, but only two needed additional active treatment (surgery). Recurrence or progression was observed in five patients and complete tumor ablation in another five: in one case it was not documented. At the time of the reports, five patients were NED, three DOD and three were AWED.

Ablation of lung metastases (Table 2)

Nine patients reported in two papers underwent radiofrequency ablation for lung metastases [17, 23]. The mean age of the patients was 11 years (median: 12 years). The sex and body mass were only reported in one case, a 4-year-old boy weighing 12.8 kg. The histology of the primary tumors was osteosarcoma in six, Wilms tumor in one, adrenocortical carcinoma in one and hepatoblastoma in one. The diameter of the metastases was not specified in any of the cases, but the mean volume in the eight children reported by Hoffer et al. [17] was 5 ml. However, this volume includes the excluded patients due to be older than 17 years old that could not be excluded to extract the real volume of the included patients. A total of 34 lesions (mean: 4 per patient) were treated in 45 sessions (mean: 5; median: 3). Five patients received additional chemotherapy (two of them accompanied by surgery), one underwent radiotherapy and three did not receive any other treatment. All of the treatments were CT-guided radiofrequency ablation, performed under GA. Clinical success was reported for two patients and achieved in one with adrenocortical carcinoma. Forty-five percent of the lung lesions ablated in the Hoffer's paper [17] were completely ablated after the first-time treatment with no recurrence, but again, patients older than 17 years of age could not be excluded to extract the real volume of the included patients. The length of stay in the hospital was not reported in any of the treatments. The mean overall survival of the patients was 19 months (median: 13 months). All the patients suffered complications caused by the lung radiofrequency ablation: FEV1 reduction and diaphragmatic hernia in two patients each, and pain,

Table 1 Reported ablation of malignant or aggressive benign bone and soft-tissue tumors in children

Reference	Age	Sex	Mass (kg)	Histology	Location of tumor	Size (mm)	Number of lesions	Number of ablations	Other treatment after ablation
[17]	16 years	NR	NR	Rhabdomyosarcoma	Breast metastasis	NR	1	1	Chemotherapy
[17]	13 years	NR	NR	Rhabdomyosarcoma	Bone metastasis (maxilla)	NR	1	2	Embolization, chemotherapy
[17]	16 years	NR	NR	Osteosarcoma	Bone metastasis (radius)	NR	1	1	Radiotherapy
[17]	13 years	NR	NR	Plantar fibromatosis	Soft tissue (foot)	NR	6	15	None
[17]	9 years	NR	NR	Leiomyosarcoma	Ribs	NR	2	2	Antiviral therapy
[18]	10 years	M	41	Paraganglioma	Bone metastasis (femur)	12	1	1	None
[19]	9 years	F	NR	Ewing sarcoma	Bone recurrence (sacrum)	NR	1	1 (5 needles)	Celecoxib
[20]	1 day	F	NR	Sacrococcygeal teratoma	Soft tissue primary (pelvis)	170	1	1	Embolization, surgery
[21]	14 years	F	NR	Desmoid tumor	Soft tissue (tensor fascia lata)	100	1	4	None
[21]	5 years	M	NR	Desmoid tumor	Soft tissue (lumbar muscle)	55	1	3	None
[22]	10 years	F	NR	Rhabdomyosarcoma	Soft-tissue recurrence (oral cavity)	24	1	1	None

Reference	Ablation technique	Ablation device	Anesthesia technique	Guidance technique	Technical success	Clinical success	Duration of hospitalization	Patient status	Complication	Management of complication
[17]	RFA	NR	GA	US, CT	Yes	No	NR	DOD 5 months	Pain	Symptomatic
[17]	RFA	NR	GA	US, CT	No	No	NR	DOD 5 months	Trismus	None
[17]	RFA	NR	GA	US, fluoroscopy	Yes	Yes	NR	DOD 12 months	None	
[17]	RFA	NR	GA	US, CT	No	Yes	NR	AWED 34 months	Paresthesia	None
[17]	RFA	NR	GA	CT	Yes	Yes	NR	AWED 26 months	Hypoxia	Supportive
[18]	RFA	NR	GA	CT	Yes	NR	NR	NR	Hypertension (non-blocked)	None
[19]	PCA	PerCryo	GA	CT	Yes	Yes	NR	AWED 9 months	Fecal and urinary incontinence	Supportive
[20]	RFA	NR	GA	CT	Yes	Yes	NR	NED 12 months	None	
[21]	RFA	Star-Burst XL	GA	CT	Yes	Yes	<1 day	NR	None	
[21]	RFA	Star-Burst XL	GA	US	Yes	Yes	<1 day	NR	Skin burn	Surgery
[22]	RFA	Cool-tip 20 mm	GA	CT	Yes	Yes	NR	NED 18 months	Trismus	None

All reported procedures were performed under general anesthesia

NR not reported, *M* male, *F* female, *RFA* radiofrequency ablation, *PCA* percutaneous cryoablation, *DOD* died of disease, *AWED* alive with evidence of disease, *NED* no evidence of disease

Table 2 Reported CT-guided radiofrequency ablation (RFA) of lung metastases in children

Reference	Age, y	Sex	Tumor mass, kg	Primary tumor	Treatment after ablation	Ablation technique	Electrode type	Number of lesions	Number of ablations	Technical success	Clinical success	Patient status and age at event	Complications	Management of complication
[17]	10	NR	NR	Osteosarcoma	Radiotherapy	RFA	NR	2	2	NR	NR	DOD 8 months	FEV1 reduction	Supportive
[17]	14	NR	NR	Osteosarcoma	None	RFA	NR	2	3	NR	NR	NED 48 months	Pain	Supportive
[17]	12	NR	NR	Osteosarcoma	Chemotherapy	RFA	NR	4	4	NR	NR	DOD 12 months	Hypoxia	Supportive
[17]	16	NR	NR	Osteosarcoma	Surgery, chemotherapy	RFA	NR	1	1	NR	NR	DOD 13 months	Bradycardia	Supportive
[17]	4	NR	NR	Adrenocortical carcinoma	Surgery, chemotherapy	RFA	NR	4	16	yes	NR	DOD 27 months	Diaphragmatic hernia	Surgery
[17]	16	NR	NR	Osteosarcoma	Chemotherapy	RFA	NR	6	6	NR	NR	DOD 12 months	FEV1 reduction	None
[17]	10	NR	NR	Wilms tumor	Chemotherapy	RFA	NR	9	9	NR	NR	AWED 33 months	Diaphragmatic hernia	Surgery
[17]	12	NR	NR	Osteosarcoma	None	RFA	NR	3	3	NR	NR	DOD 15 months	Dyspnea	Supportive
[23]	4	M	12.8	Hepatoblastoma	None	RFA	Cool-tip 20 mm	3	1	no	no	DOD 21 days	Bronchovascular fistula	Attempted coagulation with RFA probe

All procedures were performed under general anesthesia

NR not recorded, *M* male, *FEV1* forced expiratory volume in 1 s, *AWED* alive with evidence of disease

hypoxia, bradycardia, dyspnea and bronchovascular fistula with hemorrhage in one patient each. The treatment of the complications was surgical in two patients. In the patient with bronchovascular fistula, there was an attempt to coagulate a hemorrhage with the radiofrequency ablation needle. Supportive care was sufficient in five cases, and there was no need for treatment in the patient with FEV1 reduction. There was recurrence in one patient and progression in two. At the time of reporting, seven patients were DOD, one was AWED and one was NED. Cryoablation of lung metastases has not yet been reported in children.

Liver ablation (Table 3)

Five patients underwent liver ablation [13, 24–26]. Mean age was 4 years (median: 3 years). Three patients were female and two male. The weight was only reported for one patient (12.6 kg). The histology was hepatoblastoma in two patients, and adrenocortical carcinoma, hepatic adenoma and Wilms tumor in one each. There were two primary tumors, two metastases and one local recurrence. The diameter was reported in four cases (mean: 19 mm). Seven lesions were ablated in seven sessions. US was the image guidance (in two cases it was intraoperative) and technical and clinical success was achieved in all five cases. Mean overall survival was 44 months (median: 36 months). There were no complications and except for one patient with unreported data, no progression or tumor recurrence was described. All five patients were NED at the time of reporting.

Kidney or pancreas ablation (Table 4)

Four patients were treated with ablation for retroperitoneal tumors [27–30]. The mean age was 11 years, and all patients were female. The weight was only reported in one case (16 kg). The histology was Wilms tumor in two, juxtaglomerular cell tumor in one, and solid and papillary epithelial neoplasm of the pancreas in one patient. The ablation was performed in the kidney (2), surgical bed following nephrectomy (1) and pancreas (1). In each case the tumor was primary, except for one patient with local recurrence of Wilms tumor [28]. The median diameter of the ablated lesions was 18 mm. The diameter was unreported in one patient [28]. All of the lesions were treated with radiofrequency ablation, and in all the cases the electrode size and type were reported. A total of five lesions were ablated in six sessions. One patient subsequently received brachytherapy [28] and another surgery due to failure of the radiofrequency ablation [29]. In all the treatments GA was used; image guidance was CT in three and intraoperative US in one. Technical success was accomplished in all four cases. Clinical success was obtained in three patients. The duration of hospitalization was only specified for one procedure (1 day) [27]. Mean overall survival was 12 months. Only one patient suffered a complication (abdominal pain), but this did not require treatment. Recurrence or progression was observed in one patient. At the time of the reporting, two patients were NED, one was AWED and one had died of another cause (leukemia).

Discussion

As expected, there is very limited experience with ablation in children. Even though the manuscript summarizes the overall experience, it may not provide significant help in decision-making for surgeons/interventional radiologists to decide appropriate use of ablation use in children. The number of cases and pathology treated with these techniques is also small to draw conclusions about efficacy of ablative techniques in pediatric pathology.

This systematic review confirms that ablative therapies are feasible in children with primary, recurrent or metastatic tumors in various organs. Most reports implicitly describe treatment with palliative intent in patients that in many cases have failed to respond to almost every other available therapy. This selection for poor candidates may contribute to a failure to achieve similar results to those observed in adults.

Because pediatric cancer is relatively rare, and indications for ablative therapies are few, the only way to evaluate individual modalities in specific clinical situations will be to develop multicenter international studies.

It is notable that many published cases are poorly described, in terms of both the technical aspects of the procedures and the clinical outcomes. These deficiencies should be addressed in future research studies. To this end, we propose a minimum data set for future reports (Table 5). These include recommended data to improve the quality of the reported cases and to facilitate their interpretation in future systematic reviews and meta-analysis about pediatric tumor ablation. These data concern:

- The *patient* (age, sex, weight, target organ function tests, pain evaluation pre- and post-procedure, quality of life assessment).
- The *tumor* (tumor histology, tumor location including possible factor reducing efficacy, tumor chronology, tumor volume, tumor markers).
- The *technique* (clinical indication and clinical success definition, technical success definition, ablated volume, neoadjuvant or adjuvant therapies, type and size of electrode or antenna or probe, energy generated, ablation

Table 3 Reported ablation of liver tumors in children

Reference	Age, y	Sex	Tumor mass, kg	Histology	Tumor size, mm	Liver segments involved	Other treatment after ablation	Ablation technique	Electrode type (if RFA)	Anesthesia type	Number of lesions	Number of ablations	Guidance technique	Patient status and age at event
[24]	2	F	12.6	Adrenocortical carcinoma metastasis	15	6/7	None	PEI		GA	2	3	US	ANED 39 months
[25]	13	M	NR	Hepatic adenoma	35	6	None	RFA	NR	GA	1	1	US	ANED 24 months
[13]	2.5	F	NR	Hepatoblastoma	NR	5/8 and 8	Chemotherapy (SIOPEL-3HR)	RFA	Le Veen 35 mm	GA	2	1	US at laparotomy	ANED 96 months
[13]	3	F	NR	Wilms tumor metastasis	15	8	Chemotherapy (SIOP 2001)	RFA	Le Veen 0 mm	GA	1	1	US at laparotomy	ANED 36 months
[26]	2	M	NR	Hepatoblastoma (recurrent)	10	4	None	RFA	HiTT 20–30 mm	LA, sedation	1	1	US	ANED 24 months

All procederes were reported to be technically and clinically successful. Duration of hospitalization was not reported. No complications were reported

F female, *M* male, *NR* not reported, *PEI* percutaneous ethanol injection, *RFA* radiofrequency ablation, *GA* general anesthesia, *LA* local anesthesia

ANED alive, no evidence of disease

Table 4 Reported ablation of renal and pancreatic lesions in children

Reference	Age, y	Sex	Tumor mass, kg	Histology	Tumor diameter, mm	Location	Other treatment after ablation	Electrode type	Number of lesions	Number of ablations	Guidance technique	Duration of hospitalization	Patient status and age at event or follow-up	Complications
[27]	5	F	16	Wilms tumor	18	Kidney	None	Le Veen 20 mm	1	1	CT	1 day	AWED 14 months	None
[28]	11	F	NR	Recurrent Wilms tumor	NR	Renal fossa	Brachytherapy	Cool-tip 20 mm	1	2	CT	NR	Died of leukemia 9.5 months	None
[29]	11	F	NR	Solid-pseudopapillary neoplasm	120	Pancreas	Surgery	RITA 1500X	2	2	US at laparotomy	NR	NED 12 months	Abdominal pain, pyrexia, abnormal LFT
[30]	17	F	NR	Juxtaglomerular cell tumor	8	Kidney	none	Le Veen 35 mm	1	1	CT	NR	NED 14 months	None

NR not reported, *AWED* alive with evidence of disease, *LFT* liver function tests

All reported patients were female. All procedures were radiofrequency ablation, performed under general anesthesia, and were reported as technically and clinically successful

NED no evidence of disease

Table 5 Required data for reporting local ablation for cancer

Patient
Age[a]
Sex[a]
Weight[b]
Target organ function tests[b]
Pain evaluation pre- and post-procedure[b]
Quality of life assessment[b]
Tumor
Tumor histology[a]
Tumor location including possible factor reducing efficacy[a]
Primary, local recurrence, distant metastases[a]
Tumor volume (at least diameter)[a]
Tumor markers[b]
Technique
Clinical indication and clinical success definition[a]
Technical success definition[a]
Ablated volume[a]
Neoadjuvant or adjuvant therapies[a]
Type and size of electrode, antenna, etc., and energy generated[a]
Ablation protocol[a]
Image guidance technique[a]
Number of lesions treated[a]
Number of treatments for every lesion in a single session[a]
Number of sessions in a single lesion[a]
Complications and their level by WHO/SIR classification[a]
Hospitalization length[b]
Image follow-up technique[a]
Response criteria (RECIST, mRECIST) and response classification[a]
Cancer-related relevant endpoints
Time follow-up[a]
Overall survival[a]
Disease-free survival[a]
Time to recurrence[a]
Time to progression[b]
Time to local recurrence[a]
Event-free survival[b]
Progression-free survival[b]

[a] Necessary

[b] Recommended

RECIST response evaluation criteria in solid tumors

mRECIST modified response evaluation criteria in solid tumors

WHO World Health Organization

SIR Interventional Radiology

protocol, image guidance technique, number of lesions treated, number of treatments for every lesion in a single session, number of sessions in a single lesion, complications and its level by OMS/SIR classification, hospitalization length, image follow-up technique, response criteria [response evaluation criteria in solid tumors, modified response evaluation criteria in solid tumors, criteria of the European Association for the Study of the Liver] response classification).

– The *cancer-related relevant endpoints* (time follow-up, overall survival, disease-free survival, time to recurrence, time to progression, time to local recurrence, event-free survival, progression-free survival).

Conclusion

Although ablative techniques are feasible and promising treatments for certain pediatric tumors, large multicenter prospective trials will be needed to establish efficacy. As ablation procedures for malignant tumors in children are infrequent, reporting data in a structured way becomes an essential instrument to perform analysis in future systematic reviews.

Conflicts of interest None.

References

1. Vogl TJ, Naguib NN, Lehnert T et al (2011) Radiofrequency, microwave and laser ablation of pulmonary neoplasms: clinical studies and technical considerations–review article. Eur J Radiol 77:346–357
2. Gangi A, Tsoumakidou G, Buy X et al (2010) Quality improvement guidelines for bone tumor management. Cardiovasc Intervent Radiol 33:706–713
3. Palussière J, Italiano A, Descat E et al (2011) Sarcoma lung metastases treated with percutaneous radiofrequency ablation: results from 29 patients. Ann Surg Oncol 18:3771–3777
4. Martin RC 2nd, McFarland K, Ellis S et al (2013) Irreversible electroporation in locally advanced pancreatic cancer: potential improved overall survival. Ann Surg Oncol 20:S443–S449
5. Lencioni R, Crocetti L (2012) Local-regional treatment of hepatocellular carcinoma. Radiology 262:43–58
6. Goldberg SN, Grassi CJ, Cardella JF et al (2009) Image-guided tumor ablation: standardization of terminology and reporting criteria. J Vasc Interv Radiol 20:S377–S390
7. European Association for Study of Liver; European Organisation for Research and Treatment of Cancer (2012) EASL-EORTC clinical practice guidelines: management of hepatocellular carcinoma. Eur J Cancer 48:599–641, Erratum in: Eur J Cancer 48:1255–1256
8. Vogl TJ, Wissniowski TT, Naguib NN et al (2009) Activation of tumor-specific T lymphocytesafter laser-induced thermotherapy in patients with colorectal liver metastases. Cancer Immunol Immunother 58:1557–1563
9. Mizukoshi E, Yamashita T, Arai K et al (2013) Enhancement of tumor-associated antigen-specific T cell responses by radiofrequency ablation of hepatocellular carcinoma. Hepatology 57:1448–1457
10. Rao P, Escudier B, de Baere T (2011) Spontaneous regression of multiple pulmonary metastases after radiofrequency ablation of a single metastasis. Cardiovasc Intervent Radiol 34:424–430
11. Ahmed M, Moussa M, Goldberg SN (2012) Synergy in cancer treatment between liposomal chemotherapeutics and thermal ablation. Chem Phys Lipids 165:424–437

12. Ikuta S, Kurimoto A, Iida H et al (2012) Optimal combination of radiofrequency ablation with chemoradiotherapy for locally advanced pancreatic cancer. World J Clin Oncol 3:12–14
13. van Laarhoven S, van Baren R, Tamminga RY et al (2012) Radiofrequency ablation in the treatment of liver tumors in children. J Pediatr Surg 47:e7–e12
14. Rimondi E, Mavrogenis AF, Rossi G et al (2012) Radiofrequency ablation for non-spinal osteoid osteomas in 557 patients. Eur Radiol 22:181–188
15. Hill RH 3rd, Shiels WE 2nd, Foster JA et al (2012) Percutaneous drainage and ablation as first line therapy for macrocystic and microcystic orbital lymphatic malformations. Ophthal Plast Reconstr Surg 28:119–125
16. Kim YJ, Baek JH, Ha EJ et al (2012) Cystic versus predominantly cystic thyroid nodules: efficacy of ethanol ablation and analysis of related factors. Eur Radiol 22:1573–1578
17. Hoffer FA, Daw NC, Xiong X et al (2009) A phase 1/pilot study of radiofrequency ablation for the treatment of recurrent pediatric solid tumors. Cancer 115:1328–1337
18. Pappas L, Seefelder C (2009) Anesthetic consideration for radiofrequency ablation of a suspected paraganglioma metastasis in a child. Paediatr Anaesth 19:913–914
19. Lessard AM, Gilchrist J, Schaefer L et al (2009) Palliation of recurrent Ewing sarcoma of the pelvis with cryoablation and somatosensory-evoked potentials. J Pediatr Hematol Oncol 31:18–21
20. Cowles RA, Stolar CJ, Kandel JJ et al (2006) Preoperative angiography with embolization and radiofrequency ablation as novel adjuncts to safe surgical resection of a large, vascular sacrococcygeal teratoma. Pediatr Surg Int 22:554–556
21. Ilaslan H, Schils J, Joyce M et al (2010) Radiofrequency ablation: another treatment option for local control of desmoid tumors. Skelet Radiol 39:169–173
22. Nashida Y, Yamakado K, Kumamoto T et al (2007) Radiofrequency ablation used for the treatment of frequently recurrent rhabdomyosarcoma in the masticator space in a 10-year-old girl. J Pediatr Hematol Oncol 29:640–642
23. Burgoyne LL, Pereiras LA, Laningham F et al (2008) Near-fatal acute bronchovenous fistula in a child undergoing radiofrequency ablation of a metastatic lung tumor. Paediatr Anaesth 18:1131–1133
24. Hara F, Kishikawa T, Tomishige H et al (2003) A child with adrenocortical carcinoma who underwent percutaneous ethanol injection therapy for liver metastasis. J Pediatr Surg 38:1237–1240
25. Rocourt DV, Shiels WE, Hammond S et al (2006) Contemporary management of benign hepatic adenoma using percutaneous radiofrequency ablation. J Pediatr Surg 41:1149–1152
26. Ye J, Shu Q, Li M et al (2008) Percutaneous radiofrequency ablation for treatment of hepatoblastoma recurrence. Pediatr Radiol 38:1021–1023
27. Brown SD, Vansonnenberg E, Morrison PR et al (2005) CT-radiofrequency ablation of pediatric Wilms tumor in a solitary kidney. Pediatr Radiol 35:923–928
28. Gandhi S, Meech SJ, Puthawala MA et al (2005) Combined computed tomography-guided radiofrequency ablation and brachytherapy in a child with multiple recurrences of Wilms' tumor. J Pediatr Hematol Oncol 27:377–379
29. Sugito K, Kusafuka T, Hoshino M et al (2010) Application of radiofrequency ablation for giant solid pseudopapillary tumor of the pancreas. Pediatr Int 52:e29–e31
30. Kirkham AP, Ho SG, Paterson RF et al (2008) Treatment of a juxtaglomerular tumor with radiofrequency ablation. Urology 71:168.e1-4