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Evolving Experience With Direct Puncture Therapeutic Embolization for Adjunctive and Palliative Management of Head and Neck Hypervascular Neoplasms

John C. Chaloupka, MD; Sundeep Mangla, MD; Daniel C. Huddle, OD; Toni C. Roth, MD; Sanchayeeta Mitra, MD; Douglas A. Ross, MD; Clarence T. Sasaki, MD

Objectives: **The use of percutaneous, direct puncture therapeutic embolization (DPTE) of hypervascular head and neck neoplasms is a relatively new modality that may be used to supplement or supplant conventional endovascular transarterial embolization. Although the preliminary clinical experience reported by a single group has been favorable, extensive case series experience is lacking. This prompted us to review our recent clinical experience with these techniques to determine safety, efficacy, and emerging role in the overall neurointerventional therapeutic armamentarium.** ***Study Design:*** **A retrospective analysis of the previous 34 consecutive cases of hypervascular tumors undergoing DPTE referred to our service for therapeutic devascularization was performed.** ***Methods:*** **Complete case record review was undertaken. Twenty-six of 34 cases involved DPTE of head and neck neoplasms. Conventional diagnostic angiography was performed for therapeutic planning and to assist in precise localization. When performed, standard microcatheter transarterial embolization techniques were used either before or after attempted DPTE. Cyanoacrylate embolic mixtures (n-butyl cyanoacrylate [NBCA], lipiodol, powdered tungsten) were used in 21 of 24 cases, and absolute ethanol in 3 of 24. Direct puncture angiography of the targeted tumor neovasculature was always performed before DPTE.** ***Results:*** **Twenty-four of 26 cases had technically successful DPTE. Combined transarterial embolization with DPTE was used in 16 of 24 cases, although for the last 12 cases, 9 were treated predominantly or exclusively by DPTE. There were no major or minor clinical complications, and there was one asymptomatic technical complication. Total or near-total devascularization was achieved in all cases. All preoperative cases had excellent hemostasis within the resected tumor bed.** ***Conclusions:*** **Our results lend further support to the safety and efficacy of DPTE in the management of hypervascular neoplasms of the head and neck. With our increasing experience, this technique is evolving into a primary therapeutic modality for optimal tumor devascularization.** ***Key Words:*** **Head neoplasms, neck neoplasms, therapeutic embolization, interventional neuroradiology, experimental.**

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INTRODUCTION

The highly vascular nature of a variety of primary and metastatic neoplasms of the head and neck often pose formidable challenges for optimal surgical management. In the past, profuse bleeding during resection of such tumors was frequently encountered, which could result in various complications, such as excessive intraoperative blood loss, incomplete resection, and increased postoperative morbidity associated with inadvertent injury to normal surrounding structures that were poorly seen within the operative field.[1–3]

Consequently, the value of preoperative therapeutic embolization of hypervascular head and neck tumors has become more widely recognized.[4] Although basic transarterial embolization techniques have been performed for more than 25 years, it is only within the past decade that contemporary endovascular therapy has evolved to permit experienced operators a safer and more effective means of achieving optimal tumor devascularization before open

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From the Section of Interventional Neuroradiology, Department of Radiology (J.C.C., S.M.), University of Iowa Hospitals and Clinics, Iowa City, Iowa; the Section of Neuroradiology, Department of Radiology (D.C.H., T.C.R.), and the Section of Otolaryngology, Department of Surgery (S.M., D.T.S.), Yale University School of Medicine, New Haven, Connecticut; the Section of Interventional Neuroradiology (D.C.H.), Department of Radiology, Massachusetts General Hospital, Boston, Massachusetts; and the Central Illinois Neuroscience Foundation (T.C.R.), Bloomington, Illinois.

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Send Reprint Requests to John C. Chaloupka, MD, Section of Interventional Neuroradiology, Department of Radiology, JPP 3891, University of Iowa Hospitals and Clinics, 200 Hawkins Drive, Iowa City, IA 52242-1077, U.S.A.

resection.[1-3] This enhanced capability has been mostly a result of technological and technical developments in superselective transarterial navigation and embolization. However, despite these substantial advances in contemporary superselective microcatheterization and embolization, there often remain various challenges, risks, and limitations that have precluded universally excellent results.[1,4]

In recognizing these problems, an unconventional alternative approach to devascularization of craniofacial tumors has been recently described, simply referred to as direct puncture tumor embolization (DPTE).[4] This technique, which was partially based on prior descriptions of direct puncture of osseous spinal tumors,[5,6] superficial high- and low-flow vascular malformations,[7,8] and certain visceral neoplasms,[9-11] involves percutaneous placement of a needle directly within the neoplasm, through which certain liquid embolic agents (e.g., cyanoacrylate suspensions or absolute ethanol) are injected into the tumor neovasculature after confirmation by test injection of contrast media.

Although the preliminary clinical experience with this novel technique has been favorable, extensive case series experience is lacking. Furthermore, identification of the optimal technical parameters of DPTE for head and neck applications and its potential role(s) within the overall neurointerventional armamentarium are not well defined.[13]

Since our group has had increasing experience with DPTE applied to a wide spectrum of hypervascular neoplasms, we were prompted to review our evolving clinical experience with this potentially powerful addition to the neurointerventional armamentarium applied to the head and neck.

PATIENTS AND METHODS

Patients

Case records consisting of diagnostic imaging studies and reports, neurointerventional imaging studies, operative reports, clinic notes, and hospital charts were retrospectively reviewed for the previous 34 consecutive patients referred to the interventional neuroradiology service for therapeutic devascularization of hypervascular neoplasms in which DPTE was used. The types of tumors treated included bone and soft tissue metastases (renal, thyroid, melanoma), paragangliomas, squamous cell carcinomas, meningiomas, juvenile nasopharyngeal angiofibromas, schwannomas, aneurysmal bone cysts, an adenocystic adenocarcinoma, and a sarcoma.

Twenty six of these 34 cases were categorized as head and neck neoplasms occurring in the following locations: nasopharynx, oropharynx, hypopharynx, oral cavity/palate, orbit, jugular foramen, carotid space, buccal space, calvaria, supraclavicular space, and cervical spine (Table I).

Conventional Angiographic and Embolization Techniques

Patients undergoing therapeutic embolization by endovascular and/or DPTE techniques received either local anesthesia and neuroleptanalgesia or general anesthesia, depending on a number of considerations. Factors that tended to influence the use of general anesthesia included certain anatomic locations of the tumors (e.g., skull base, orbits), the anticipated risk of certain complications (e.g., airway obstruction), need for more precise localization of tumors targeted for DPTE, and the potential for producing severe pain that may not be controllable under routine awake sedation.

Standard percutaneous transfemoral arterial access was obtained for all patients at least once during their management to identify the specific arterial supply and degree of hypervascularity of the targeted neoplasms. Diagnostic neuroangiography was initially performed by selective catheterization and injection of nonionic contrast agent (iohexol) in which high-resolution digital subtraction angiography (DSA) was obtained in multiple projections. Depending on the anatomic location and size of the tumor, the following craniocervical arteries were injected: internal carotid, external carotid, vertebral, subclavian, costocervical, and thyrocervical arteries. The results of the diagnostic angiograms were used to assess the feasibility of conventional transarterial embolization, compartmentalization of blood supply, and the appropriate control angiographic projections required to monitor the progress of therapy.

Superselective catheterization and DSA of feeding arteries were performed when transarterial therapeutic embolization was planned. Typically, therapeutic embolization was performed using microparticle suspensions as previously described in detail.[1] In brief, polyvinyl alcohol (PVA) particles (Contour, Boston Scientific, Fremont, CA) of varying size (45–250 μm) were suspended in iohexol and injected intermittently through 1-mL syringes. In cases where very distal superselective catheterization of a feeding artery resulted in exclusive supply to the targeted tumor, the smaller size range of particle sizes was used (45–150 μm) to achieve maximal distal penetration of emboli into the tumor microvasculature. In all other situations the next larger size range (150–250 μm) was used to decrease the risk of serious ischemic injury to normal surrounding tissues. Transarterial particulate embolization was performed under continuous fluoroscopic guidance until nearly complete stasis of blood flow within each feeding pedicle was achieved. Subsequently, in most cases proximal occlusion of the feeding pedicles was also performed using either gelatin foam pledgets (Gelfoam, Upjohn, Kalamazoo, MI) or platinum microcoils (Target Therapeutics, Fremont, CA). Coils or pledgets also were used to isolate tumor vessels from normal territories by occluding distal branches not supplying tumor. Successful embolization was determined by failure to opacify an embolized artery on subsequent selective angiography.

Direct Puncture Tumor Embolization Technique

The detailed multiplanar angiographic evaluation of the hypervascular neoplasms was used as the initial "road map" for proper three-dimensional delineation of the targeted neovasculature and selection of ideal positioning for monitoring therapy. In many cases the targeted tumors were relatively superficial, permitting gross localization by simple palpation. More precise localization of the targeted components of the tumor was then usually possible by fluoroscopic road mapping after selective or superselective injection of the arterial supply of the malformation. Based on the anatomic location of the hypervascular neoplasm and the optimal visualization of its neovasculature, a fluoroscopic imaging projection was selected in one plane to permit the easiest skin entry to target pathway. Ideally, this imaging projection would be coaxial to the planned needle tract. However, for some deeper tumors this localization approach was not always successful, owing to obstructions form functionally important structures (e.g., carotid artery, salivary glands, cranial nerves) and bone. In such cases orthogonal and nonorthogonal imaging projections (either with monoplanar or biplanar fluoroscopy) would be used in combination with road mapping to direct the needle into the targeted portion of the malformation. As an al-

TABLE I.
Patient Results.

Patient No.	Age (y)	Sex	Histology	Location	Therapy	Outcome	Complications
1	46	F	Glomus	Lt. carotid sheath	ta (pva, microcoils) dpte (histoacryl)	Near-total dv	Embo-0
2	47	M	rJNA	Lt. face	dpte (histoacryl)	Subtotal dv	Embo-0
3	79	M	Meningioma	Rt. orbit	ta (pva, mc) dpte (histoacryl)	Near-total dv	Embo-0
4	68	M	Renal cell	C6,C7 vertebrae	ta (bo, mc, pva) dpte (histoacryl)	Near-total dv	Embo-0
5	60	F	Glomus	Lt. carotid sheath	dpte (histoacryl)	Near-total dv	Embo-0
6	53	F	Squamous cell	Oropharynx	dpte (ethyl alcohol)	Cessation of hemorrhage	Embo-0
7	53	M	Schwannoma	Rt. parapharyngeal	ta (mc) dpte (histoacryl)	Total dv	Embo-0
8	58	M	Glomus	Lt. cervical, ectopic	dpte (histoacryl)	Near-total dv	Embo-0
9	56	M	Squamous cell	Lt. anterior chest, posterior neck and shoulder	dpte (histoacryl, ethyl alcohol)	Cessation of hemorrhage	Embo-0
10	63	F	Schwannoma	Lt. carotid sheath	ta (mc) dpte (histoacryl)	Near-total dv	Embo-0
11	55	M	Renal cell	Lt. orbit, ethmoid sinus, nasopharynx	ta (pva, mc, gf) dpte (histoacryl)	Total dv	Embo-0
12	47	M	Renal cell	C5,C6 vertebrae	ta (pva, mc) dpte (histoacryl)	Total dv	Embo-0
13	46	M	rJNA	Lt. face	ta (pva, gf, mc) dpte (histoacryl)	Total dv	Embo-0
14	82	F	Glomus	Lt. CPA	ta (pva, mc) dpte (histoacryl)	Total dv	Embo-0
15	43	F	Glomus	Lt. carotid sheath	ta (pva, mc) dpte (histoacryl)	Total dv	Embo-0
16	55	F	Spindle cell ca	Soft palate	ta (pva, mc, gf) dpte (histoacryl)	Near-total dv	Embo-0
17	55	F	Renal cell	C6 vertebra	ta (pva, mc) dpte (histoacryl)	Near-total dv	Embo-0
18	44	M	Meningioma	Lt. temporal calvarium	ta (pva, mc, gf) dpte (unsuccessful)	Subtotal dv	Embo-0 unsuccessful dpae
19	61	F	Adenocystic ca	Rt. maxilla	ta (pva, gf) dpte (histoacryl)	Subtotal dv	Embo-0
20	30	F	Glomus	Lt. jugular foramen	ta (pva, mc) dpte (histoacryl)	Subtotal dv	Embo-0
21	37	M	Sarcoma	Rt. TMJ	ta (pva, mc) dpte (unsuccessful)	Near-total dv	Embo-0 unsuccessful dpae
22	66	F	Glomus	Palate	ta (pva, mc) dpte (histoacryl)	Total dv	Embo-0
23	48	M	Meningioma	Lt. temporal calvarium	ta (pva, mc, gf) dpte (histoacryl)	Total dv	Embo-0
24	48	M	Melanoma	Lt. axilla, neck, and shoulder	ta (pva, mc, gf) dpte (histoacryl)	Near-total dv	Embo-0
25	65	F	Squamous cell ca	Tongue	dpte (ethyl alcohol)	Total dv	Embo-0
26	50	M	Glomus	Rt. carotid sheath	dpa (histoacryl)	Subtotal dv	Embo-0

ca = cancer; ta = transarterial; dpte = direct puncture tumor embolization; pva = polyvinyl alcohol particles; mc = microcoils; gf = Gelfoam; dv = devascularization; Lt. = left; Rt. = right; CPA = cerebellopontine angle; TMJ = temporomandibular joint.

ternative, more precise and reliable localization was occasionally needed to enhance technical success and minimize risk of complication, using a combined fluoroscopic and computed tomography (CT) imaging guidance procedure developed by our group.

To facilitate optimal direct puncture of many of the tumors referred for treatment, somewhat unconventional approaches were often used (e.g., transoral, transpalatal, transnasal, transorbital) (Figs. 1–4). These approaches were favored because of either proximity to the tumor or appropriate margins for safety from vital neurovascular structures. Various needles and injection techniques were used, which changed over time as the result of a combination of increased clinical experience and the results of experiments performed in a previously described animal model developed by the senior author.[12] Standard nonionic contrast

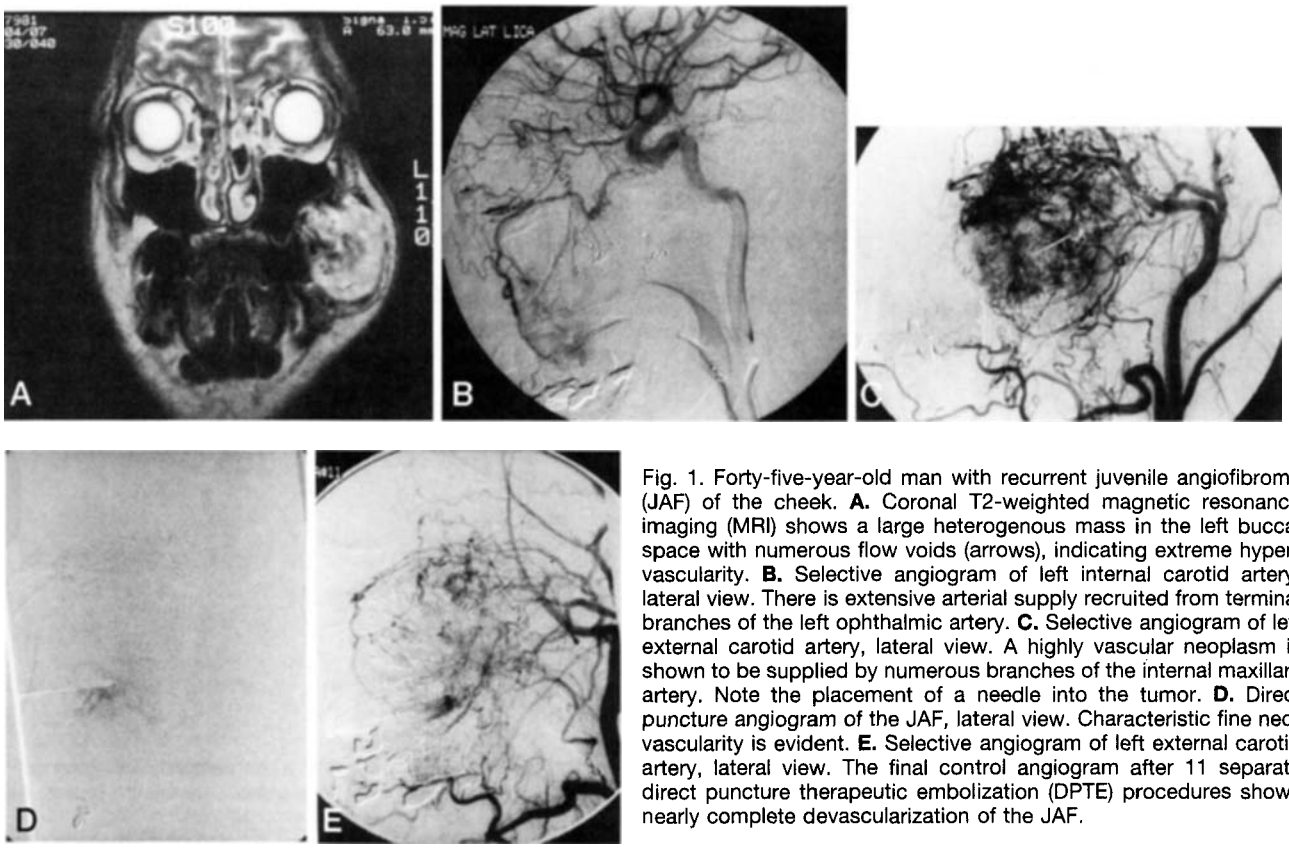

Fig. 1. Forty-five-year-old man with recurrent juvenile angiofibroma (JAF) of the cheek. **A.** Coronal T2-weighted magnetic resonance imaging (MRI) shows a large heterogenous mass in the left buccal space with numerous flow voids (arrows), indicating extreme hypervascularity. **B.** Selective angiogram of left internal carotid artery, lateral view. There is extensive arterial supply recruited from terminal branches of the left ophthalmic artery. **C.** Selective angiogram of left external carotid artery, lateral view. A highly vascular neoplasm is shown to be supplied by numerous branches of the internal maxillary artery. Note the placement of a needle into the tumor. **D.** Direct puncture angiogram of the JAF, lateral view. Characteristic fine neovascularity is evident. **E.** Selective angiogram of left external carotid artery, lateral view. The final control angiogram after 11 separate direct puncture therapeutic embolization (DPTE) procedures shows nearly complete devascularization of the JAF.

media was used (iohexol) for direct puncture angiography. Pertinent modifications in puncture and injection technique included the use of smaller-caliber needles (typically, 23 or 25 gauge), prepuncture priming of the needles with undiluted iohexol (to minimize volumes of contrast agent injected into the tumor), and elimination of requiring blood reflux through the needle before injecting contrast media or embolic agent (as described by Casasco et al.[4]).

Gentle injections of iohexol through the needle were performed using either monoplanar or biplanar DSA to determine the density and extent of neovascularity, as well as the venous drainage of the corresponding microvascular bed (Figs. 1D and 4D). Embolization of the tumor neovasculature was then performed with a liquid acrylic embolic mixture consisting of n-butyl cyanoacrylate (NBCA) (Histoacryl, Braun, Germany), iodinized oil (lipiodol), and small quantities of powdered tungsten (NycoMed, Princeton, NJ) (Fig. 3C). The details of preparation and delivery techniques for this embolic mixture used by our group have been described elsewhere.[14]

The liquid adhesive mixtures were slowly injected with a 1-mL luer lock syringe under continuous fluoroscopic visualization. The ratio of NBCA to iodinized oil varied from 1:1 to 1:3, favoring more dilute suspensions of NBCA as our experience progressed. The duration of each injection varied from 20 seconds to several minutes, allowing for slow, progressive permeation of the vascular compartment until reflux into the feeding pedicles or deposition into the draining veins was observed. After waiting an additional 30 to 60 seconds to ensure complete polymerization, the needle was withdrawn from the tumor and control angiography performed to determine the extent of devascularization and to target the next neovascular compartment. The technique was repeated as many times as necessary to achieve maximal devascularization of the neoplasm.

For preoperative embolizations, patients typically would undergo surgical resection within 24 to 48 hours of treatment. Patients undergoing palliative embolizations were usually observed for 12 hours before discharge. All patients received prophylactic antibiotics (1 g cefazolin, IV) at the time of DPTE. Postembolization analgesics and anti-inflammatory agents were not routinely administered.

Assessment of Therapeutic Efficacy

The technical success of all embolization procedures was determined by the degree of residual neovascularity and parenchymal staining observed on control angiography in orthogonal planes at the completion of therapy. This permitted a semiquantitative assessment of the extent of tumor devascularization by the following grading system: 1, poor (0%–30%); 2, moderate (30%–70%); 3, subtotal (70%–95%); 4, near-total (95%–99%); and 5, total (100%).

The degree of intraoperative blood loss within the resected tumor bed was only qualitatively assessed by the surgeon into the following categories: minor, moderate, and severe.

RESULTS

Within the referral group (N = 26), the following hypervascular neoplasms were treated: four metastases (three renal cell, one melanoma), eight paragangliomas (glomus caroticum, glomus jugulare, glomus vagale, ectopic nasopharyngeal and cervical), three squamous cell carcinomas, three meningiomas, two juvenile nasopharyngeal angiofibromas, two schwannomas, two aneurysmal bone cysts, one adenocystic adenocarcinoma, and one sarcoma. Although some of these tumors (e.g., adenocystic adenocarcinoma, squamous cell carcinomas, and schwannomas) are usually not hypervascular, findings on cross-

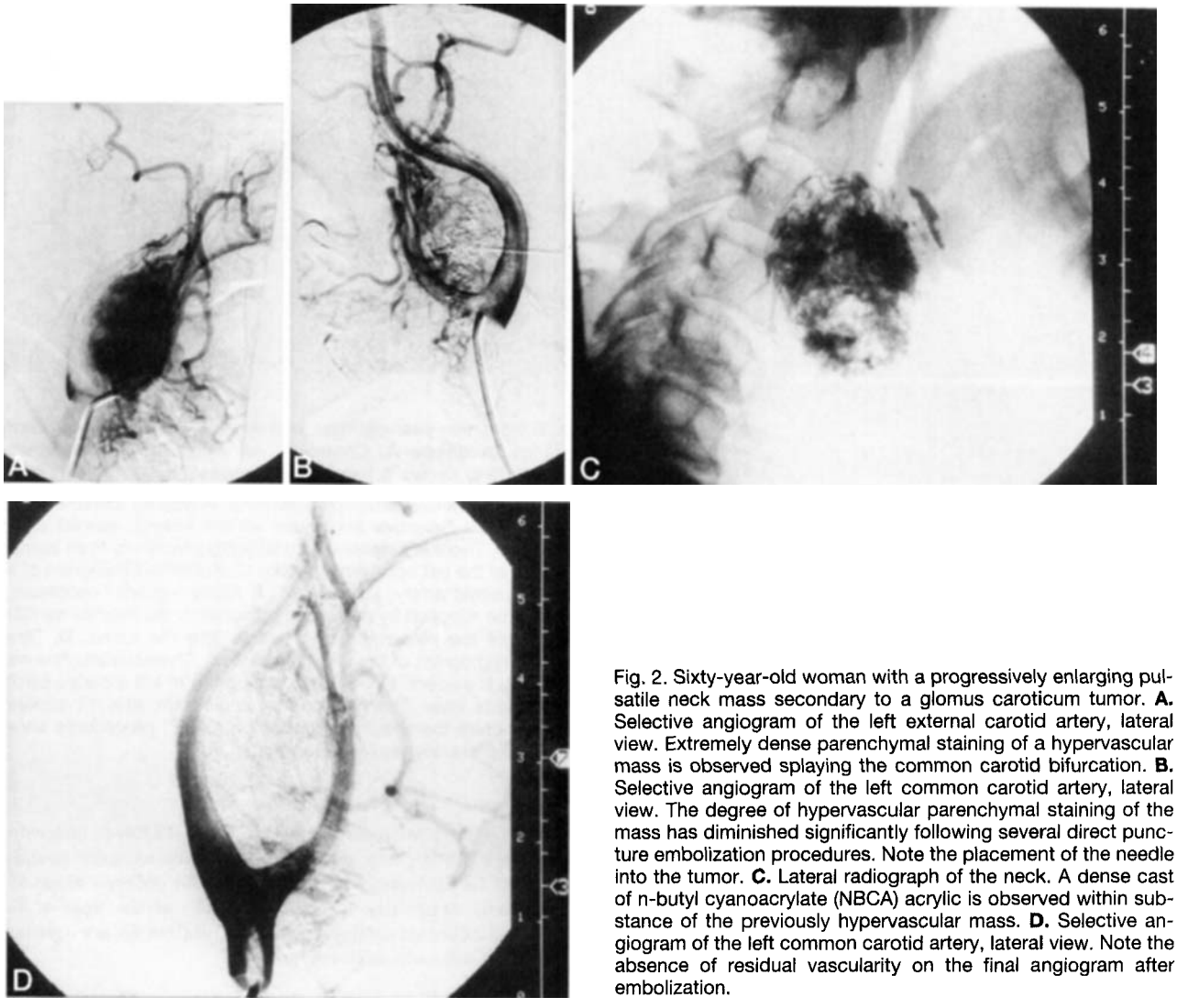

Fig. 2. Sixty-year-old woman with a progressively enlarging pulsatile neck mass secondary to a glomus caroticum tumor. **A.** Selective angiogram of the left external carotid artery, lateral view. Extremely dense parenchymal staining of a hypervascular mass is observed splaying the common carotid bifurcation. **B.** Selective angiogram of the left common carotid artery, lateral view. The degree of hypervascular parenchymal staining of the mass has diminished significantly following several direct puncture embolization procedures. Note the placement of the needle into the tumor. **C.** Lateral radiograph of the neck. A dense cast of n-butyl cyanoacrylate (NBCA) acrylic is observed within substance of the previously hypervascular mass. **D.** Selective angiogram of the left common carotid artery, lateral view. Note the absence of residual vascularity on the final angiogram after embolization.

sectional imaging (e.g., prominent enhancement) or on clinical examination (e.g., bleeding on direct inspection) prompted diagnostic angiographic evaluation for confirmation.

Embolization was performed in preparation for surgery in 20 cases, while the remaining 6 cases were treated for palliative control of hemorrhage, pain, or growth. The technical and clinical outcomes are summarized in Table II. Direct puncture tumor embolization as an adjunctive or primary modality was successfully employed in 24 of 26 cases (92%). The two patients with unsuccessful attempted DPTE already had undergone extensive transarterial embolization at the same session. In both cases, poor visualization of significant residual neovasculature on direct puncture DSA was noted, which suggested that additional embolotherapy was not necessary. These patients subsequently underwent uneventful surgical resections, although one developed a delayed recurrence of an interosseous meningioma 4 years later, which was then successfully embolized at that time with a combination of DPTE and conventional transarterial embolization.

A combination of transarterial embolization and DTPE was used in several cases (16/24), while DPTE was used exclusively in 8 cases. In 21 cases, a liquid acrylic adhesive mixture (NBCA/iodinized mineral oil and tungsten powder) was used for DPTE, and absolute ethanol mixed with metrizamide was used either exclusively or in combination with acrylic in the remaining three cases.

An interesting trend in the use of DPTE techniques was observed in our series. Early in our experience, there was a tendency to be very conservative in using DPTE, reserving any such attempts for use only after all conventional transarterial embolization routes had been exhausted. In contrast, a review of the previous 12 consecutive patients with head and neck hypervascular neoplasms revealed that nine (75%) had therapeutic devascularization performed either exclusively or predominantly by DPTE. In the latter group of patients undergoing predominantly DPTE, this technique was used as the primary therapeutic modality, followed later by some supplemental transarterial embolization, as needed.

Of the 24 successful sessions of DPTE (with or without transarterial embolization), 83% of cases had either total or near-total devascularization, while the remaining 17% (n = 4) had subtotal devascularization. No "poor" or "moderate" grades of devascularization were noted. Of the

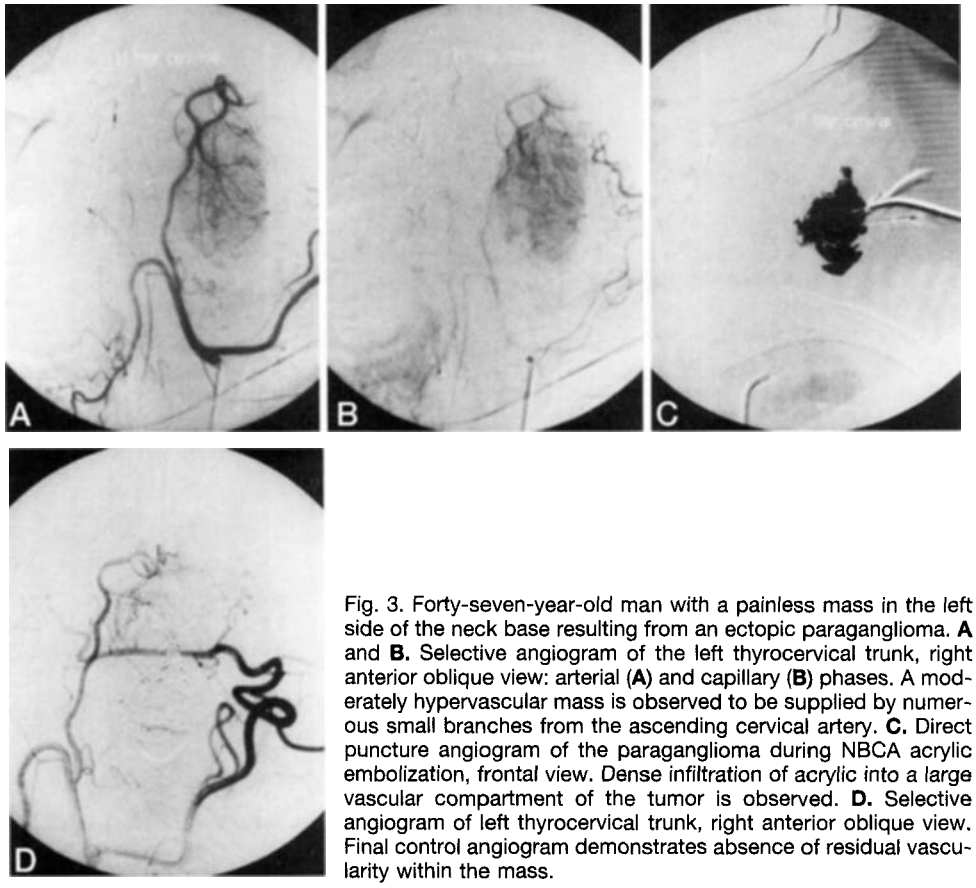

Fig. 3. Forty-seven-year-old man with a painless mass in the left side of the neck base resulting from an ectopic paraganglioma. **A** and **B.** Selective angiogram of the left thyrocervical trunk, right anterior oblique view: arterial (**A**) and capillary (**B**) phases. A moderately hypervascular mass is observed to be supplied by numerous small branches from the ascending cervical artery. **C.** Direct puncture angiogram of the paraganglioma during NBCA acrylic embolization, frontal view. Dense infiltration of acrylic into a large vascular compartment of the tumor is observed. **D.** Selective angiogram of left thyrocervical trunk, right anterior oblique view. Final control angiogram demonstrates absence of residual vascularity within the mass.

eight patients treated exclusively with DPTE (six, acrylic; one, ethanol; and one, acrylic/ethanol), six (75%) had total devascularization, while the remaining two (25%) achieved subtotal devascularization. In the two cases of direct puncture ethanol embolization, an important objective of the therapy was to produce significant palliative mass reduction of the tumor, which was accomplished.

There were no major or minor clinical complications from DPTE using either acrylic or ethanol. This included lack of neurological deficits, cranial nerve palsies, and cosmetic problems (e.g., skin ulceration and sloughing). There was one technical complication, consisting of inadvertent reflux of a minute quantity of acrylic embolic mixture into the internal carotid circulation resulting in asymptomatic microembolization of a distal branch of the middle cerebral artery. This complication occurred at the very beginning of our experience, a consequence of overinjection of acrylic into the tumor neovasculature that resulted in retrograde filling of a small feeding external carotid branch.

The effectiveness of preoperative devascularization of neoplasms eventually subjected to surgical resection was uniformly judged to be excellent in all patients. Total resection or subtotal debulking of tumors was reported in all cases, the latter occurring as planned owing to the stage and degree of invasion of the neoplasm. The operating surgeons reported encountering minimal or no bleeding from the tumor bed, which greatly facilitated resections and diminished morbidity, through a combination of substantially less than expected intraoperative blood loss, better visualization of surrounding normal tissues within the operative field, and greater demarcation of pathological margins. The latter result was a consequence of the characteristic blue-black "staining" of the embolized tumor by the tantalum and blue acrylic used for the embolizations.

In the two patients undergoing exclusively DPTE in response to hemorrhage from their tumors, excellent palliation was achieved, consisting of a combination of acute cessation of hemorrhage, pain reduction, and tumor debulking.

DISCUSSION

Before the advent of preoperative endovascular therapeutic embolization, the treatment of highly vascular neoplasms within any anatomic site often has posed formidable challenges for safe and effective surgical resection. Most of these challenges are either directly or indirectly related to the profuse bleeding that may be typically encountered during manipulation and instrumentation of such neoplasms.

Until recently, conventional approaches to therapeutic preoperative devascularization of hypervascular neoplasms had been exclusively focused on transarterial embolization techniques. Certainly, within the last decade these transarterial embolization techniques have rapidly evolved, expanding the current capabilities of contemporary endovascular therapy. However, despite the overall enhancements in

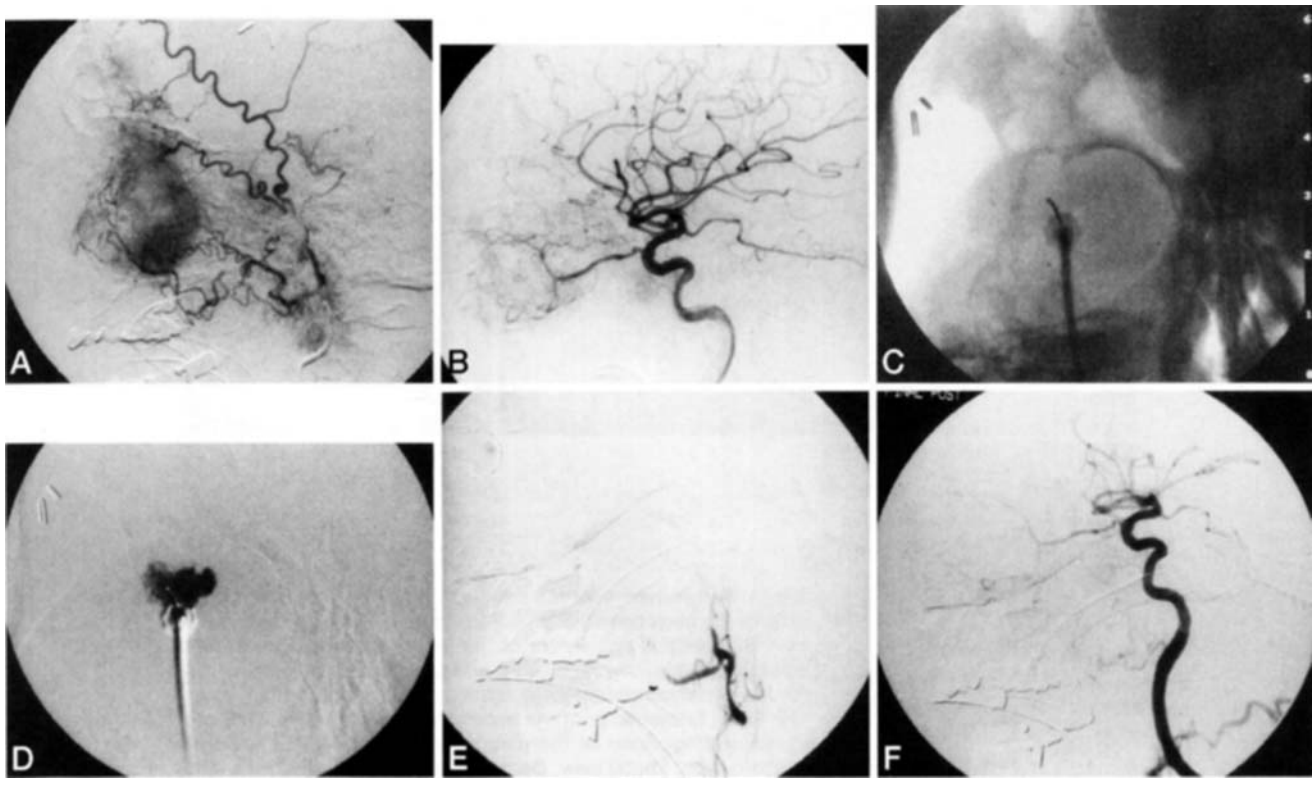

Fig. 4. Sixty-eight-year-old man with recurrent interosseous meningioma involving the right orbit and maxillary sinus. **A.** Selective angiogram of the right external carotid artery, lateral view. Numerous small branches of the sphenopalatine, middle meningeal, and superficial temporal arteries are observed to contribute to the hypervascularity. **B.** Selective angiogram of the right internal carotid artery, lateral view. Significant contributions from orbital branches of the ophthalmic artery are present. **C** and **D.** Frontal radiograph of right orbit, direct puncture angiogram of the meningioma, frontal view. A needle is shown traversing the right orbit, with its tip positioned deeply within the mass. The angiogram demonstrates a significant vascular compartment of the mass, amenable to embolization. **E** and **F.** Selective angiogram of the right external carotid artery, lateral view. No residual neovascularity is identified on the final control angiogram, after embolization.

transarterial embolization approaches, there continues to be numerous limitations, restrictions, and challenges that frequently preclude attaining the desired goal of maximal, yet safe therapeutic devascularization.[1,4]

There are several reasons for these shortcomings. For example, the feeding arteries supplying a targeted hypervascular neoplasm may be inaccessible owing to one or a combination of the following factors: extremely small size, unfavorable angle or site of origin (i.e., ophthalmic artery), excessive tortuosity, or previous surgical ligation of the proximal external carotid trunk. In addition, the presence of dangerous extracranial-to-intracranial anastomoses and the risk of inadvertent reflux into the intracranial circulation increases the risk of inadvertent neurological sequelae. Also, depending on the size range selection of PVA and extent of superselective purchase of the microcatheter, particulate transarterial embolization of the feeding pedicles to many of the most intensely hypervascular tumors (e.g., hemangiopericytoma, paraganglioma) may fail to provide effective preoperative devascularization, owing to the inability to deposit adequate quantities of emboli into the neovasculature.

In recognizing these problems with contemporary transarterial endovascular embolization, Casasco et al.[4] described the unconventional alternative approach to devascularization of craniofacial tumors by direct puncture of the tumor neovasculature (referred to as DPTE). This group reported their clinical experience with DPTE of head and neck disease in 17 cases, most of which (14/17) were embolized by the so-called direct puncture acrylic embolization (DPAE) technique. The remaining three cases underwent direct puncture ethanol embolization (DPEE). The tumors encountered in their series included nasopharyngeal angiofibroma, hemangiopericytoma, glomus jugulare, and hypervascular metastases of the calvaria. They reported no technical failures or major complications and an outstanding overall degree of devascularization for all cases (including 100% obliteration in 14/17 cases). There was only one minor complication, consisting of a temporary case of Horner syndrome.

Surprisingly, despite the very favorable preliminary clinical experience reported by Casasco et al.,[4] no additional case series experience with this technique has been reported. This is at least in part related to the lack of extensive application of DPTE (particularly with cyanoacrylate embolic mixtures) within the United States, which probably derives from the following issues: *1.* reluctance to use cyanoacrylates that remain unapproved by the U.S. Food and Drug Administration, *2.* higher technical demands for effective use of cyanoacrylates, *3.* lack of formal training and experience by many practitioners, and *4.* uncertainty about optimal technique.

Our group has been very fortunate to have increasing experience with these relatively new direct puncture embolization techniques, both in clinical practice and in a laboratory setting. Originally, in recognizing the shortcomings of conventional transarterial embolization, we sought to find adjunctive techniques that might permit achieving the desired goal of maximal therapeutic devascularization.[14] Therefore, based on our earlier experience with percutaneous direct puncture embolization techniques used for both high- and low-flow head and neck vascular malformations[1] and the preliminary experience of Casasco et al.,[4] we began very conservatively to use DPTE on selected cases of hypervascular neoplasms in various anatomic locations. Typically, these earlier cases were selected because of either anticipated or actual extreme difficulties encountered after attempting conventional superselective transarterial microcatheterization techniques.

Within a relatively short time it became clear that DPTE (particularly DPAE) could be performed fairly easily and safely and usually resulted in excellent technical outcomes. However, despite this favorable preliminary experience with DPAE, we recognized various ambiguities and potential limitations of the technique that were mostly related to the paucity of well-defined and validated technical parameters for its optimal execution. This prompted us to pursue a systematic study of the important technical requirements and objective outcome end points (i.e., the clinical, angiographic, and histopathological effects) of DPAE through the development and systematic study of an appropriate animal model.[12] These studies are mostly ongoing, although one practical result of their execution has been the systematic experimentation with different hardware (e.g., needles, syringes, stopcocks), injection techniques of contrast media and embolic agents, and formulations of acrylic embolic mixtures and the recognition of different patterns of distribution of the embolization mixtures that have allowed our group to make appropriate adjustments in performing these procedures in a clinical setting (as outlined in "Patients and Methods").

Based on our cumulative clinical experience, as well as preliminary data from experiments conducted on an animal model of hypervascular neoplasms that we have recently developed,[12,13] it appears that DPTE has the ability to produce a very complete filling of the tumor microvascular bed. In the case of DPAE, this creates a distinctive intratumoral casting of the neovascular bed that is likely to result in more complete and irreversible occlusion of the embolized vessels when compared with traditional transarterial endovascular techniques. Consequently, it is our impression that DPTE with acrylic embolic mixtures may provide a level of total devascularization (as defined not only by postembolization control angiography, but also by intraoperative bleeding encountered from the tumor resection) which is frequently not possible with most conventional transarterial embolization techniques. Of course, these preliminary clinical impressions eventually will need to be scientifically validated by a well-designed randomized clinical trial.

Another potential benefit of this technique is that the intratumoral microvascular casting from darkly colored components of the embolic mixture (e.g., tungsten powder and blue dye within the cyanoacrylate) enhances the surgeon's ability to distinguish neoplasm from normal surrounding tissues. Such enhanced visibility is likely to increase the probability of achieving complete surgical resection when feasible.

With regard to DPEE, it is likely that the high permeability of absolute ethanol permits excellent penetration not only into the tumor neovasculature, but also into the surrounding tumor cells. Therefore this embolic agent probably has the dual effect of inducing thrombotic occlusion of the neovasculature and direct cytotoxicity of surrounding tumor cells. Such putative mechanisms explain the preference for using this embolic agent when palliative procedures are planned for treating acute or chronic tumor hemorrhages, mass debulking, and growth retardation. Of course, the high permeability of this agent also is a major disadvantage, since there is higher risk of nontarget deposition into surrounding normal tissues. This could be potentially problematic in many head and neck anatomic sites, where critical neurovascular structures and functionally important organs (e.g., eye, major salivary glands) are frequently in close proximity to many hypervascular tumors.

Overall, our experience parallels that of Casasco et al.,[4] in that DPTE could be performed with a high degree of technical success and effectiveness and a low rate of complications. Our initial conservative application of DPTE in approximately the first half of the series may give the false appearance of limited applicability of the technique. However, as noted in "Results," there has been an increasing trend toward using DPTE (particularly DPAE) as a "first-line" therapeutic modality for approaching most head and neck hypervascular tumors. This trend is similar to that also reported by Casasco et al.[4]

CONCLUSION

DPTE of hypervascular neoplasms using either liquid acrylic embolic mixtures or absolute ethanol, or both, can be performed safely and effectively in a wide range of superficial and deep anatomic sites of the head and neck. In our experience, these therapeutic embolization techniques allow greater latitude in performing more effective adjunctive preoperative or primary palliative therapeutic devascularizations. We were able to consistently achieve excellent devascularization of some of the most hypervascular neoplasms clinically encountered (e.g., paragangliomas, renal cell carcinoma metastases) using DPTE with cyanoacrylate. Similar degrees of devascularization can be achieved with absolute ethanol, although the high diffusibility of ethanol may increase the risk of inadvertent injury to surrounding normal tissues. However, in cases where palliative mass reduction is also desired, DPTE using ethanol may be preferable, because of its higher cytotoxicity and permeability throughout an embolized tumor.

The role of DPTE in the overall armamentarium of therapeutic embolization techniques for head and neck disease appears to be evolving. In our clinical practice we are increasingly using DPTE as a preferred alternative to conventional transarterial embolization for both preoper-

ative and palliative devascularization of many head and neck hypervascular neoplasms. However, until more cumulative experience is obtained with DPTE, a clearly defined set of parameters for selection of a preferred embolization approach is probably premature.

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