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Multidisciplinary Virtual Three-Dimensional Planning of a Forequarter Amputation With Chest Wall Resection

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We present the case of a 74-year-old man with a history of a squamous cell carcinoma in the left axilla. The patient underwent a multidisciplinary surgical resection through an extended forequarter amputation with thoracic wall resection and reconstruction. With regard to the complexity of the case, three-dimensional virtual reality–based patient-specific reconstructions were used as a supplemental tool to conventional computed tomography imaging to plan the procedure. With this report, we aim to stimulate further research to improve and automate the workflow and to bring virtual and augmented reality reconstructions into the surgical theater of the future.

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A forequarter amputation is a radical ablative surgical procedure that includes the resection of the entire upper extremity, the scapula, and the clavicle.[1,2] Forequarter amputation can offer a potential curative treatment in a localized malignancy of the shoulder and axillary region, or can serve as palliative therapy if patients have uncontrollable clinical complications such as pain, functional loss, ulceration, or infections. However, forequarter amputation is a mutilating procedure and may result in severe complications, including phantom-related pain, necrosis, and intrathoracic complications.[1,2]

In specific cases, patient anatomy can be distorted due to tumor invasion into surrounding anatomic structures. Therefore, knowledge of the spatial relation of the tumor and the surrounding structures is crucial. Consequently, a thorough and detailed preoperative assessment of patient-specific anatomy is essential.[1] The use of virtual reality (VR) to evaluate computed tomography (CT) scans in three-dimensions (3D) contributes significantly to the understanding of anatomy by the surgical team.[3,4] In addition, by improving anatomic understanding, VR contributes to discussions within multidisciplinary teams and increases patient understanding of the disease. Moreover, the use of VR could result in improved didactive methods for students and resident physicians.[5]

We present a case of a 74-year-old man with a 3-year history of a stage 3 biopsy-confirmed squamous cell carcinoma in the left axilla, with involvement of regional lymph nodes. He underwent radiotherapy in 2017 and received immunotherapy from 2019 until August 2020 in another hospital. However, recently, the patient contacted the oncologic surgeons in our hospital with a dysfunctional left arm, intractable pain, and an ulcerating wound in the left axilla with recurrent infections. Restaging imaging was performed with CT and positron emission tomography (PET)-CT, which revealed a stage 3 tumoral process (increasing in size from 2019 to 2020, from 69 to 90 mm; Figure 1).

Owing to the extensiveness and complexity of the tumor, with invasion into the thoracic wall and subclavicular neurovascular bundle, we used 3D-VR-based patient-specific reconstructions for surgical planning supplemental to conventional CT-imaging. The 3D-VR reconstruction was based on contrast-enhanced CT and created using a segmentation method and VR workstation (MedicalVR, Amsterdam, Netherlands)[3] (Figure 2; Video 1). Based on two-dimensional and 3D planning, we decided to perform a multidisciplinary (thoracic, oncologic, and plastic/reconstructive surgery) extended left-sided forequarter amputation with partial thoracic wall resection (rib 1-4) and subsequent reconstruction. The

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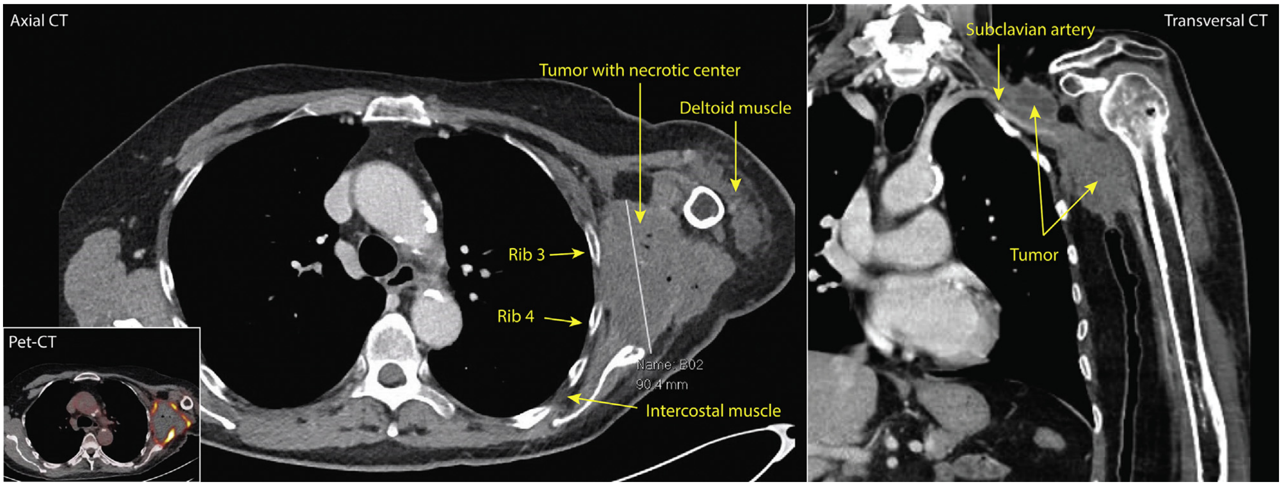

FIGURE 1 Computed tomography (CT) and positron emission tomography-computed tomography (PET-CT) images of tumorous process in left axilla region.

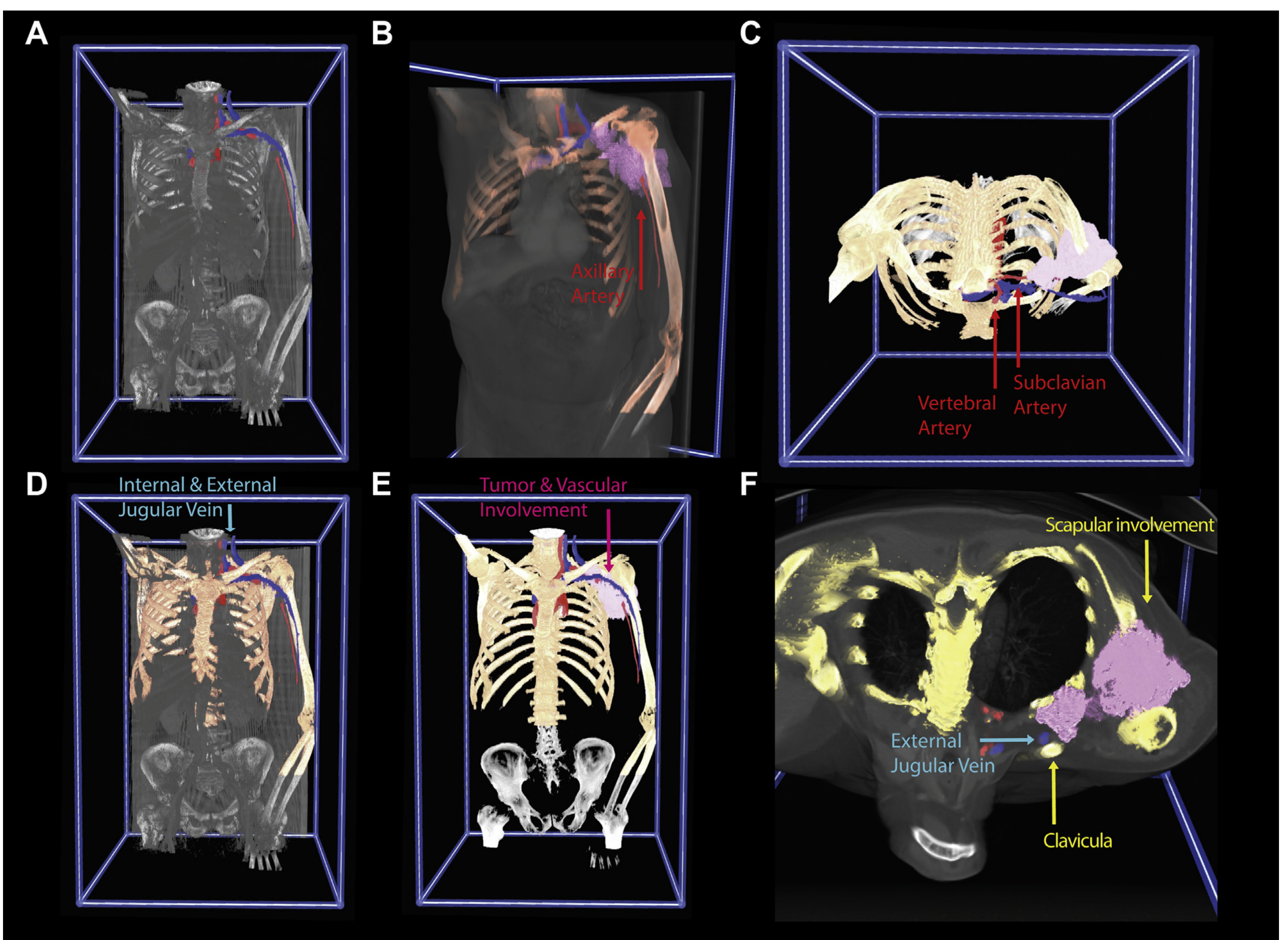

FIGURE 2 Screen captures of virtual reality–based three-dimensional reconstruction of conventional computed tomography images: (A) arteries (red) and veins (blue); (B) axillar artery completely encased by tumor; (B-F) bony structures (yellow) and tumor highlighted (pink). (B, C, E, F) Tumor has close proximity to superior costae, scapula, and clavicula.

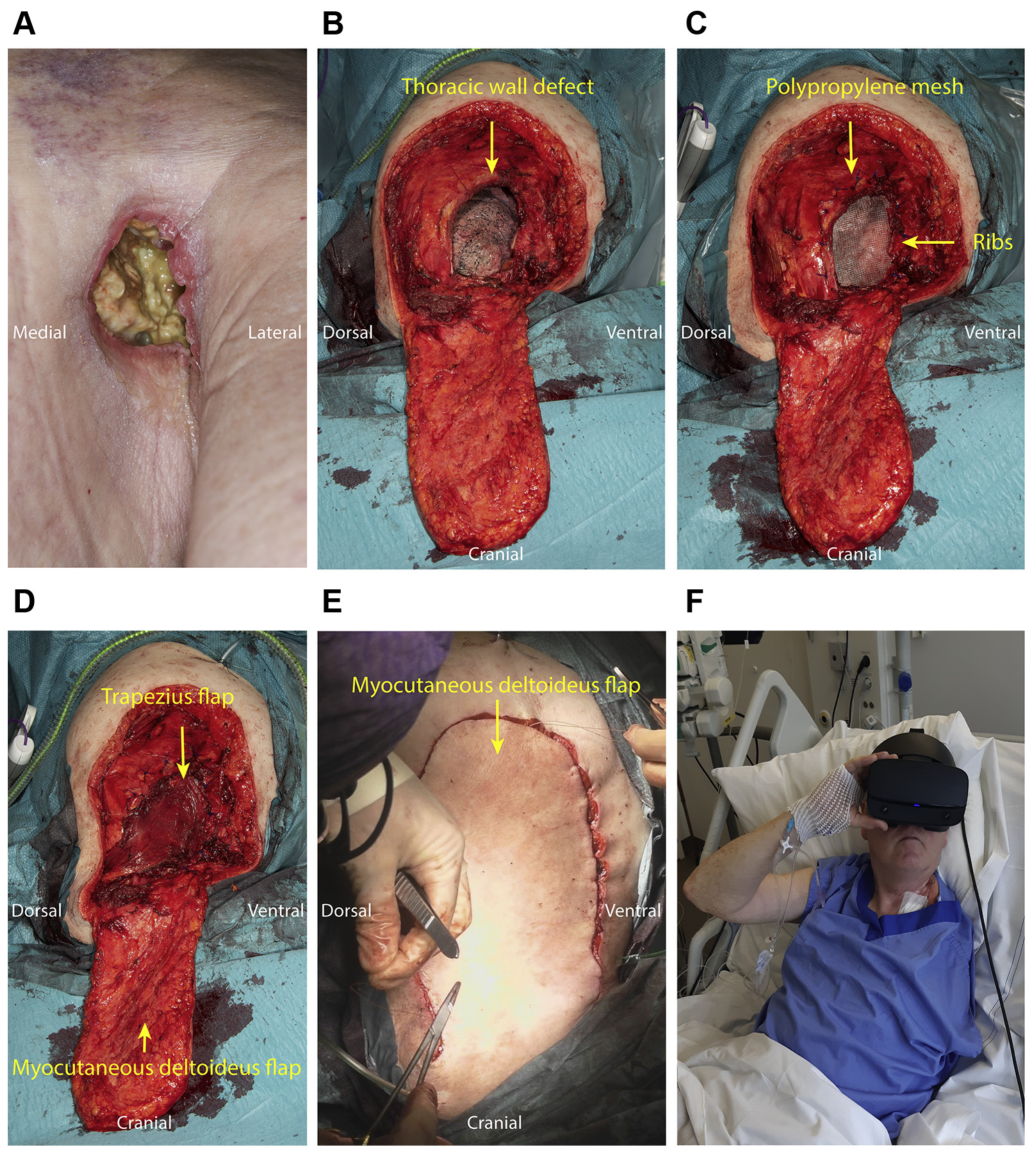

FIGURE 3 (A) Ulcerating wound preoperatively. (B-E) Intraoperative images after forequarter amputation with extended thoracic wall resection of first two ribs. (C-E) Primary closure with polypropylene mesh, trapezius muscle, and myocutaneous flap. (F) Patient wearing head-mounted display in surgical ward postoperatively.

3D-VR reconstruction allowed us to appreciate that the vertebral artery and jugular veins were unaffected. Therefore, they could be spared and used as a medial landmark intraoperatively. All involved surgeons thoroughly reviewed the conventional and VR-based imaging preoperatively. The patient was shown the CT scan preoperatively, and the VR rendering postoperatively (Figure 3E).

For the operation, first a left-sided fasciocutaneous circular forearm flap was dissected for closure of the thoracic defect. Subsequently, the forequarter amputation was carried out with adequate surgical margins.[1,2] Then, the subclavian vessels (lateral to jugular veins and vertebral artery) were identified, ligated, and transected. Next, thoracic wall involvement was determined, and revealed tumor invasion in only the first two ribs (Figure 3A). Consequently, a more limited en bloc thoracic wall resection was performed than initially planned. A polypropylene mesh combined with a well-vascularized trapezius muscle and deltoideus myocutaneous flap were used for primary closure, obviating the need for the forearm flap (Figures 3B-3D).

Postoperative pathology examination of the specimen specified the diagnosis as a basal cell carcinoma with adenoid and squamoid differentiation with extensive ingrowth of the axillary nerve. Because of the discrepancy with the initial pathology diagnosis, revision of the biopsy specimen was performed at our pathology department, where it was specified as a morpheaform basal cell carcinoma. The tumor had a diameter of 8 cm and the margins were clear. The patient recovered uneventfully and was discharged 13 days after surgery. Postoperatively, he had phantom pain, which was significantly less than the preoperative pain, and was treated adequately with multimodal pain treatment.

COMMENT

When preparing for a complex oncologic surgical resection, surgeons depend on preoperative two-dimensional imaging to visualize anatomy and to plan a radical resection. This case report illustrates the use of a novel method to visualize a patient-specific 3D reconstruction in VR. This method facilitated the visualization and understanding of the patient's anatomy relatively to the highlighted structures (Figure 2) and improved the surgeons' and patient's periprocedural knowledge.

For adequate 3D reconstructions, preferably high-resolution contrast-enhanced CT should be used. However, neither CT nor VR completely corresponded with the intraoperative anatomy, as a more limited rib resection (two instead of four) could be performed. This discrepancy might be caused by a different patient positioning. During CT imaging, the patient's arm was placed along his body, whereas intraoperatively, it was placed laterally from the thoracic wall, which possibly caused shifting of the tumor toward the ribs. Moreover, precise segmentation of anatomic structures is essential in 3D-based planning, which was challenging in this case. Tumor invasion could not be ruled out, neither proved, as was also confirmed by a radiologist. In the future, standardization of segmentation by, for example, artificial intelligence, and furthermore using augmented reality to fuse 3D models and physical view would be desirable.[5]

In conclusion, virtual 3D planning using a head-mounted display is a feasible and useful method to prepare for oncologic surgery. With adequate surgical planning beforehand, the procedural time can be relatively short, possibly reducing complications. That could specifically be useful in complex and multidisciplinary surgical cases. In this specific case, 3D-VR enabled fast recognition of anatomic structures that could be spared during an extended forequarter amputation. In addition, 3D-VR provided a useful and visually attractive method for patient teaching, which was appreciated greatly by this patient. We hope that this report stimulates further research to improve and automate the workflow to shape the future of digital surgery.

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