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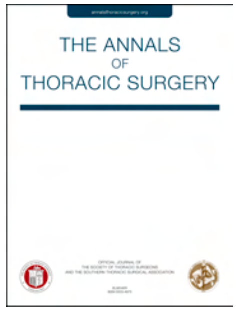

Multidisciplinary Virtual 3D Planning of a Forequarter Amputation with Chest Wall Resection

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Multidisciplinary Virtual 3D Planning of a Forequarter Amputation with Chest Wall Resection

Running head: 3D Planning of Forequarter Amputation

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Abstract

We present a case of a 74-year-old male patient, 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, 3D virtual reality-based patient-specific reconstructions were used as a supplemental tool to conventional computed tomography-imaging in order 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 theatre of the future.

A forequarter amputation (FQA) is a radical ablative surgical procedure that includes the resection of the entire upper extremity, the scapula, and the clavicle[1,2]. FQA 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, FQA 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 anatomical 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 3D, contributes significantly to the understanding of anatomy by the surgical team[3,4]. Additionally, by improving anatomical 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 male patient, with a three-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 was referred to 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 2019-2020 from 69 to 90 mm)(Figure 1).

Due 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 as published previously[3] (Figure 2, Supplemental Video 1). Based on 2D 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 3D-VR reconstruction allowed 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).

Surgery

First a left-sided fasciocutaneous circular forearm flap was dissected for closure of the thoracic defect. Subsequently, the FQA 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, which 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 (Figure 3B-D). Postoperative pathological examination of the specimen specified the diagnosis as a basal cell carcinoma (BCC) with adenoid and squamoid differentiation with extensive ingrowth of the axillary nerve. Because of the discrepancy with the initial pathological diagnosis, revision of the biopsy specimen was performed at our pathology department, where it was specified as a morpheaform BCC.

The tumor had a diameter of 8 cm and the margins were clear. The patient recovered uneventful and was discharged 13 days after surgery. Postoperatively, he experienced phantom-pain, which was significantly inferior than the preoperative pain, and was treated adequately with multimodal pain-treatment.

Comment

When preparing for a complex oncological surgical resection, surgeons depend on preoperative 2D-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 a high-resolution contrast-enhanced CT should be used. However, both CT and VR did not completely correspond with the intraoperative anatomy, since a more limited rib resection (2 instead of 4) 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, while intraoperatively was placed laterally from the thoracic wall, which possibly caused shifting of the tumor towards 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, which was also confirmed by a radiologist. In the future, standardization of segmentation by e.g. 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. Due to adequate surgical planning beforehand, the procedural time can be relatively short, possibly reducing complications. This 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 FQA. In addition, 3D-VR provided a useful and visually attractive method for patient teaching, which was appreciated a lot 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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Figure Legends

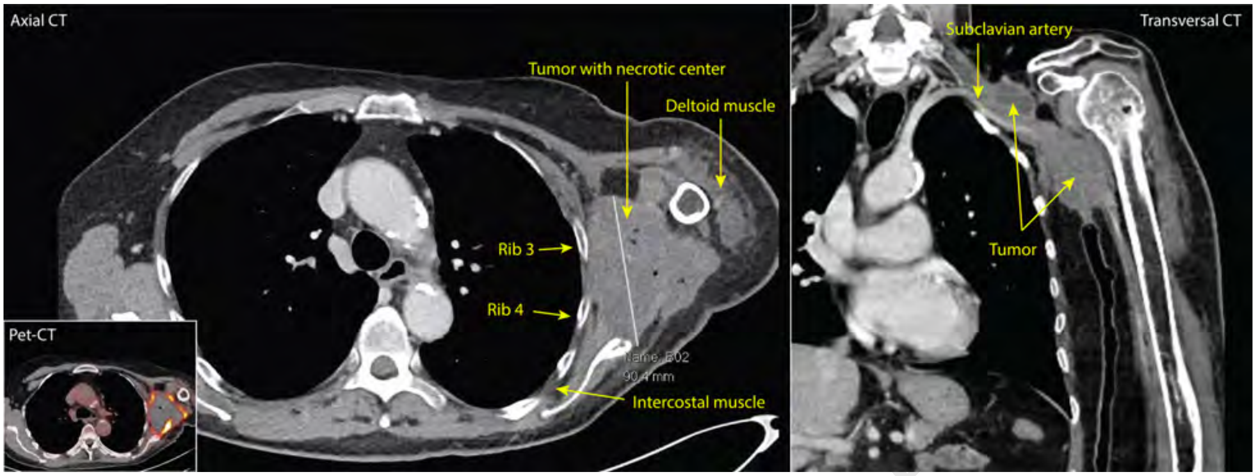
Figure 1. Computed tomography (CT) and positron emission tomography-CT (PET-CT) image of the tumorous process in the left axilla region.

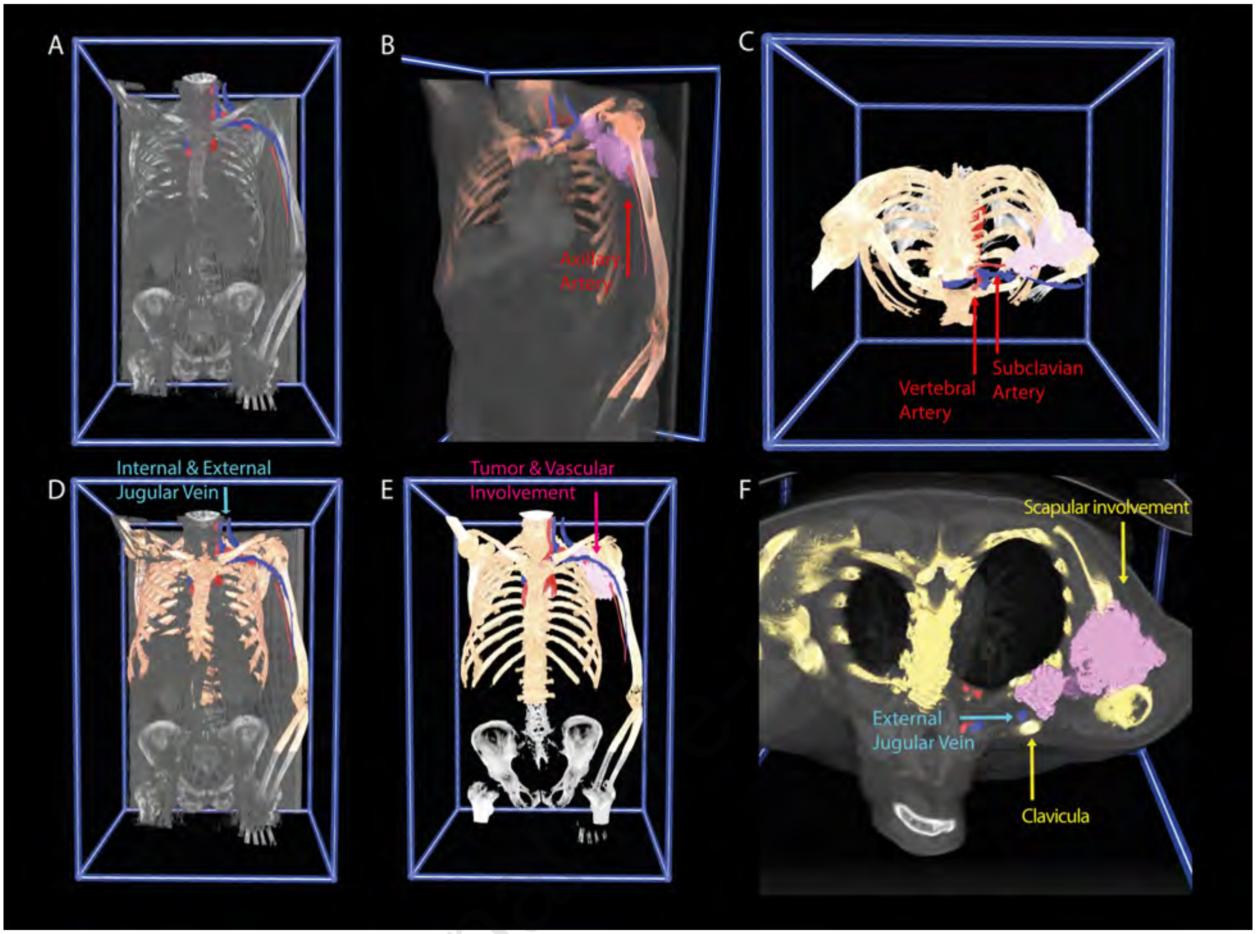
Figure 2. Screen-captures of VR-based 3D reconstruction of conventional CT images.

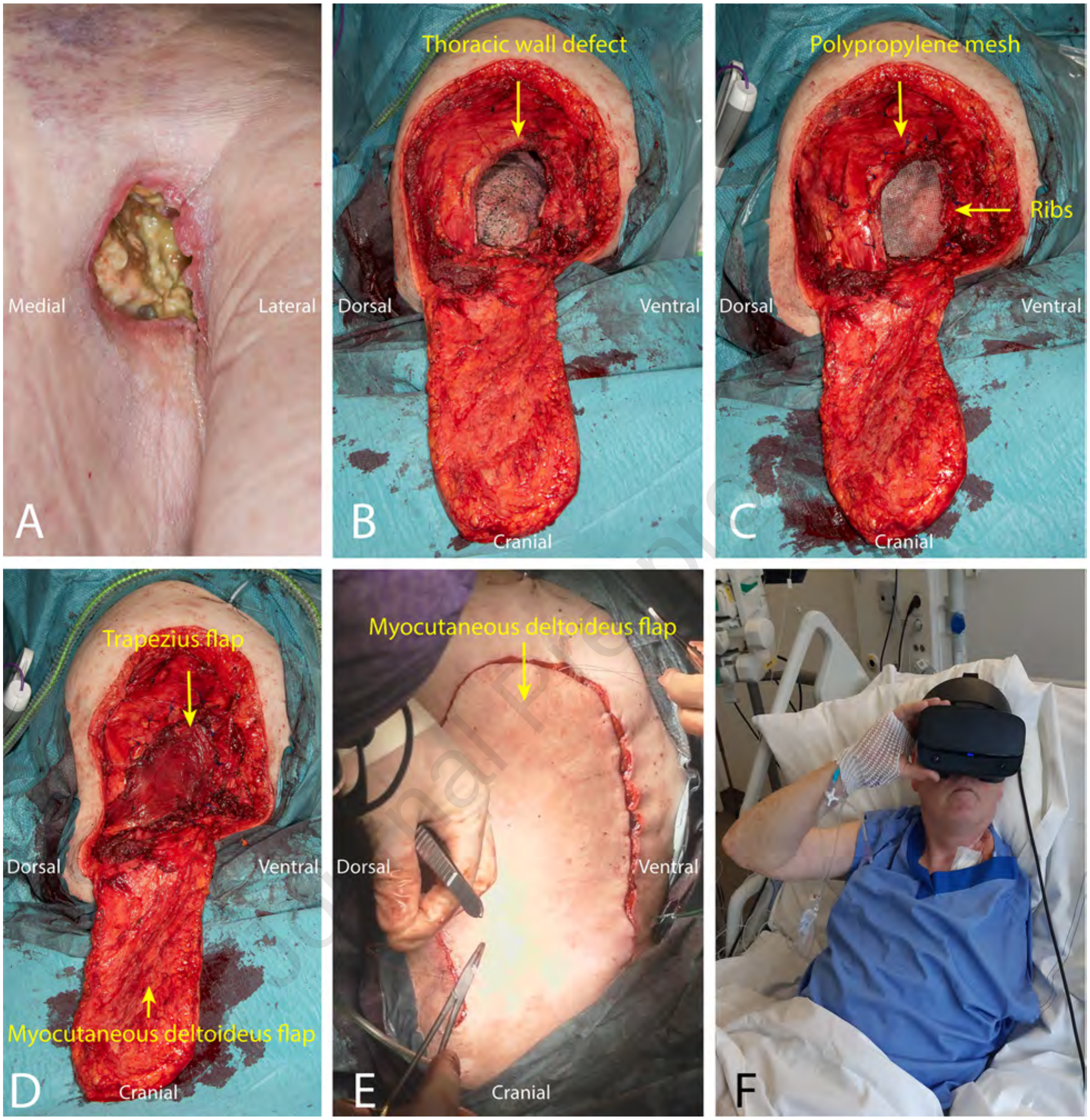
(A) Arteries (red) and veins (blue) are highlighted. (B) The axillar artery is completely encased by the tumor. (B-F) Bony structures (yellow) and the tumor are highlighted (pink). (B,C,E,F) The tumor has a close proximity to the superior costae, scapula and clavicula.

Figure 3. Intraoperative images and patient teaching

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


Axial CT
Tumor with necrotic center
Deltoid muscle
Rib 3
Rib 4
Intercostal muscle
Pet-CT
Subclavian artery
Transversal CT
Tumor


A
B
Axillary Artery
C
Vertebral Artery
Subclavian Artery
D
Internal & External Jugular Vein
E
Tumor & Vascular Involvement
F
Scapular involvement
External Jugular Vein
Clavicula


Medial
Lateral
A
Thoracic wall defect
Dorsal
Ventral
B
Cranial
Polypropylene mesh
Ribs
Dorsal
Ventral
C
Cranial
Trapezius flap
Dorsal
Ventral
Myocutaneous deltoideus flap
D
Cranial
Myocutaneous deltoideus flap
Dorsal
Ventral
E
Cranial
F