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Digital mapping of resected cancer specimens: The visual pathology report

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ABSTRACT

Background: The current standard-of-care pathology report relies only on lengthy written text descriptions without a visual representation of the resected cancer specimen. This study demonstrates the feasibility of incorporating virtual, three-dimensional (3D) visual pathology reports to improve communication of final pathology reporting.
Materials and methods: Surgical specimens are 3D scanned and virtually mapped alongside the pathology team to replicate grossing. The 3D specimen maps are incorporated into a hybrid visual pathology report which displays the resected specimen and sampled margins alongside gross measurements, tumor characteristics, and microscopic diagnoses.
Results: Visual pathology reports were created for 10 head and neck cancer cases. Each report concisely communicated information from the final pathology report in a single page and contained significantly fewer words (293.4 words) than standard written pathology reports (850.1 words, $p < 0.01$).
Conclusions: We establish the feasibility of a novel visual pathology report that includes an annotated visual model of the resected cancer specimen in place of lengthy written text of standard of care head and neck cancer pathology reports.

Introduction

Surgical pathology is a subspecialty of pathology dedicated to the gross examination, microscopic analysis, and diagnostic reporting of tissue removed during surgery. For oncological specimens, pathologists are tasked with diagnosing, grading, and staging the tumor as well as determining margin status. For head and neck cancer, margin status is the most important prognostic factor and significantly impacts further treatment.[1,2] A close margin is an adverse pathological feature for which adjuvant radiotherapy (RT) is recommended,[3] and a positive surgical margin requires either adjuvant chemoradiotherapy or surgical re-resection.[4,5]

The existing pathology report format relies on written text descriptions of the gross appearance of the specimen, tumor, and margins as well as a list of sites and sections that are selected for analysis.[6] The written report is typically the only remaining record of the resected specimen given that its structural integrity is disrupted during gross examination and remaining tissue may be disposed of 2 weeks following the sign-out of the final pathology report.[7] For complex head and neck cancer surgeries such as oral cavity composite resections, this often leads to lengthy written descriptions with minimal visual representation available for reference. Whereas recent work has focused on improving the current pathology report format with synoptic reporting, templates, and section summaries,[8,9] these efforts continue to rely on written text from which it is difficult to envision the exact location of close or positive margins, given that the majority of the cancer care team has never seen the specimen.

To address this lack of visual data available for pathology reporting, we have developed a protocol to create patient-specific, 3D scanned models of resected cancer specimens (visual pathology reports) that serve as a visual record of pathological processing to clearly demonstrate sites of inking and margin sampling.[10] These visual pathology reports may enhance communication among members of the oncological care team, as well as between the prosector who performs the gross examination and the pathologist signing out the final report.[10] We have also described a case report of an innovative, multimedia pathology reporting format.[11] In this case series, we further envision the visual pathology report format and

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demonstrate the utility of incorporating virtual 3D specimen maps to minimize the lengthy written text of the final pathology report.

Materials and methods

Patient population

This is a retrospective review of a 3D specimen map biorepository approved by the Vanderbilt University Medical Center Institutional Review Board (IRB #221597). All patients provided written consent for 3D scanning and specimen mapping of their resection specimen before surgery. Inclusion criteria were patients at least 18 years or older scheduled for definitive head and neck oncological resection. Visual pathology reports selected for inclusion in this case series were selected to sample a variety of anatomic subsites and cases requiring communication of final margin status.

3D scanning

Fresh, ex vivo head and neck oncological specimens were 3D scanned using a commercially available 3D scanner (EinScan SP, Shining 3D, Hangzhou, China) and its accompanying software (ExScan, Shining 3D). Resection specimens were rinsed and dried for optimal capture of the 3D structure and surface. The specimen was placed on the scanning turntable in the lower compartment of a custom, mobile scanning cart as shown in Fig. 1. The door to the lower compartment was closed to ensure dark conditions for optimal data capture by the 3D scanner. The scanner turntable completed eight turns (45 degrees each) to capture all sides of the specimen. The specimen was then flipped over 180 degrees to image the opposite surface and completed a second round of eight turns. The two halves of 3D data were aligned using 3-point cross-registration to create a representative 3D model of the ex vivo specimen. The resulting model was rendered into a watertight, virtual 3D mesh model, as shown in Fig. 2. The ex vivo specimen was then returned to the pathology team for routine processing. This process takes our team, on average, 8–10 min.[12,13]

Fig. 1. Mobile 3D scanning cart that may be set up outside of the OR (shown here) or pathology lab. Scanning occurs in the lower compartment of the cart and the door is closed to ensure optimal dark conditions for 3D scanning.

Virtual 3D specimen mapping

After overnight formalin fixation, specimens were grossed by a pathology assistant (PA) or resident pathologist per standard protocol. A member of the research team virtually annotated the 3D specimen model alongside the pathology team to create a 3D specimen map using computer-aided design (CAD) software (Meshmixer, Autodesk Inc., San Rafael, CA).[10] The specimen was virtually inked using colors mirroring the true inking of the specimen by pathology. Full slices through the specimen were represented using the plane cut tool to mimic how the tissue was sectioned. Each section sampled from the main specimen for margin analysis was virtually annotated on the model using color-coded boxes to represent either frozen, shave (or en face), and perpendicular sections. Each box was labeled with the letter corresponding to the cassette submitted by the prosector. Sample virtual 3D specimen maps with corresponding key are shown in Fig. 3. Once complete, representative 2D images, raw 3D scan data, and the virtual 3D specimen map were grouped by case and stored in a secure database. A full description of the step-by-step protocol for 3D scanning and specimen mapping has been previously published.[14]

Creation of the visual pathology report

Cases were retrospectively selected for the creation of 10 representative visual pathology reports. These representative cases were selected to sample a variety of anatomic subsites and final margin status. CAD software was used to rotate each map to obtain screen captures from all sides to clearly show the anatomic location of each labeled section. Multimedia software (PowerPoint, Microsoft Corporation, Redmond, Washington, USA) was utilized to create a template for use across all 10 cases. Data was extracted from the final pathology report released in the electronic medical record (EMR). The gross description of the main resection specimen, the ink color key, summary of sections, and parts of the synoptic

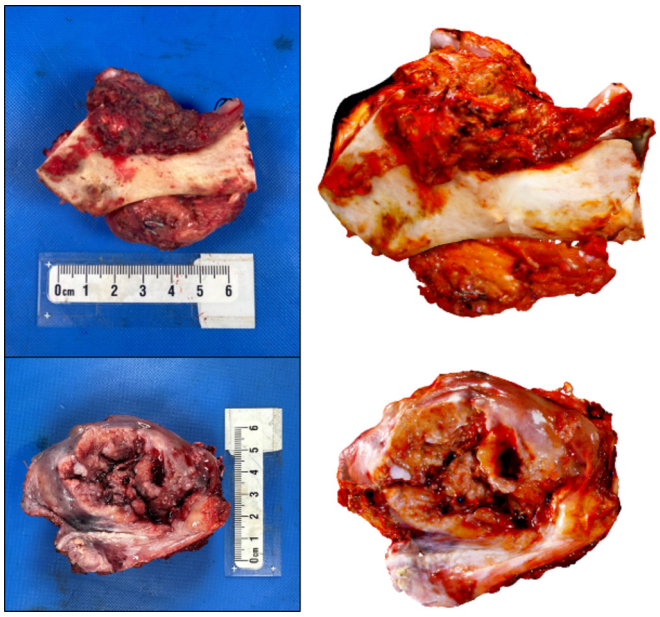

Fig. 2. Two-dimensional (2D) images of a right oral cavity composite resection (top) and right buccal mucosa (bottom) resections (left) alongside corresponding screen captures from the three-dimensional (3D) scan of each resection (right).

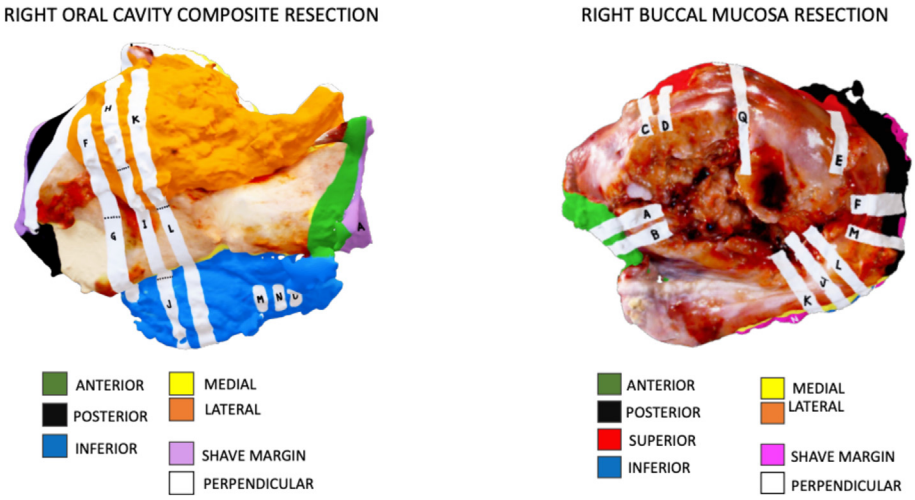

Fig. 3. Virtual 3D specimen maps (from Fig. 2 right oral cavity composite and right buccal resection) created at the time of grossing using computer-aided design (CAD) software. Corresponding key to ink colors seen below each map. White sections denote perpendicular sections, pink/purple sections denote shave margins. Each section is marked with the corresponding letter to the histology cassettes each section is submitted in.

report were incorporated as text. Images viewing each sampled margin on the virtual 3D specimen map were incorporated with their corresponding section description. Color-coded arrows were used to delineate each area of close or positive margin as well as any other feature of note, such as frozen section analysis results. Measurements were transcribed from attending pathologists' synoptic summary (microscopic measurements) as well as the PA's measurements obtained during gross examination (gross measurements). When discrepant, microscopic measurements were used in the final report. Although all sections are analyzed microscopically by an attending pathologist, only close, positive, or indeterminate microscopic margins are typically reported per the College of American Pathology guidelines for synoptic summaries.[15]

Text analysis

Number of pages and word count were analyzed for standard written pathology reports, an excerpt of the current pathology report format is shown in Fig. 4. Number of pages was determined based on total pages in

13) ORAL CAVITY COMPOSITE RESECTION:

Received fresh labeled with "_____" on the clinical and pathology labels, the MRN, and "oral cavity composite resection" is a 9.3 x 6.8 x 5.5 cm composite resection comprised of a 4.0 x 4.0 x 2.2 cm pink and glistening portion of tongue with a deep sulcus, a canine, 4 premolars, 3 molars, a 7.2 x 6.5 x 2.2 cm portion of mandible, pink and glistening gingival buccal mucosa, and tan skin with a moderate amount of adherent tan-brown and rubbery soft tissue. Received separately in the container are 4 molars (ranging from 1.8-2.2 cm). An ulceration is present extending from the tongue through the floor of mouth and gingival mucosa into the buccal mucosa. The ulceration is 0.5 cm from the anterior mucosa margin, 0.7 cm from the left mucosal margin, and 1.0 cm from the right mucosa margin. The ulceration extends through the skin and is 0.5 cm from the superior skin and soft tissue margin, 2.5 cm from the inferior skin and soft tissue margin, 2.9 cm from the right skin and soft tissue margin, and 3.5 cm the left skin and soft tissue margin. The specimen is inked as follows.

Superior, red;
Right, black;
Left, blue;
Posterior, green;
Deep, orange.

Sectioning reveals a 5.5 cm (anterior to posterior) by 5.4 cm (medial to lateral) by 3.4 cm (depth) tan-white, gritty, necrotic mass. The mass invades the base of the tongue and the mandible, 1.5 cm of the right margin and 2.2 cm the left margin. The mass is 1.7 cm from the deep soft tissue margin, 0.8 cm from the posterior soft tissue margin, and 1.7 cm from the posterior tongue margin. The remainder of the cut surface is tan-brown and rubbery to firm, tan-white, and bony. 4 partial portions of teeth are present within the cavity of the anterior ulceration. A 1.5 x 1.2 x 0.7 cm tan-brown and firm salivary gland is identified. The mass is 1.4 cm from the gland. No additional lesion or lymph node candidates are identified. The specimen is 3D photomapped. Representative sections are submitted in formalin.

Summary of Sections:
13A, right bone margin, en face, following acid decalcification 1/1;
13B-13C, left bone margin, en face, bisected, following acid decalcification, 1/1 each;
13D, mass invading mandible, following acid decalcification, 1/1;
13E, representative left skin and soft tissue margin, perpendicular, 2/1;
13F, representative right skin and soft tissue margin, perpendicular, 2/1;
13G, mass invading tongue to posterior tongue margin and soft tissue margin, 1/1;
13H, mass to deep soft tissue margin, 1/1;
13I, mass to left mucosa and soft tissue margin, perpendicular, 2/1;
13J, mass to right mucosa and soft tissue margin, perpendicular, 2/1;
13K, mass to superior skin and soft tissue margin, perpendicular, 1/1;
13L, mass to inferior skin and soft tissue margin, perpendicular, 2/1;
13M, mass to superior mucosa margin, perpendicular, 2/1;
13N, mass invading skin, 1/1;
13O-13P, representative full thickness mass, bisected, 1/1 each;
13Q, additional mass to superior skin and mucosa margin, 1/1;
13R, representative sublingual gland, 1/1.

Fig. 4. Sample page from the current standard of care final pathology report comprised of only written text with no visual representation of the resected cancer specimen.

the final pathology report document. Only words describing main resection specimen gross characteristics, margin summary sections, and data extracted from the synoptic report were included for analysis. Text describing neck dissection findings or lymph node specimens was not included in the total word count. Word counts of the standard of care written pathology report and visual pathology report were compared using a Wilcoxon signed rank test.

Results

A series of 10 cases were selected from a database of 46 virtual 3D specimen maps produced between June 1, 2023 and December 31, 2023 at a single academic institution. Virtual 3D specimen mapping occurred in tandem with regular pathological processing of the resection specimen. One research team member was present per case and spent approximately 1 hr per virtual 3D specimen map (3D scan data acquisition time and annotation). Each multimedia visual pathology report required approximately 40 min of integration of the virtual 3D specimen map and standard pathology report data.

Primary tumor anatomic subsites consisted of cancers arising from the oral cavity (6), the oropharynx (2), and the larynx (2). Oral cavity cases consisted of mucosal lip (1), tongue (1), floor of mouth (1), buccal mucosa (2), and retromolar trigone (1). All cases were mucosal p16-negative squamous cell carcinoma (SCC), with the exception of one p16-positive oropharyngeal SCC and one adenosquamous carcinoma of the larynx. The majority (70 %) of cases were pathological stage T4, with the remainder being stage T3 (20%) and T1 (10%). A close resection margin (<5 mm from invasive carcinoma on microscopy) was present in six cases. A focally positive margin (invasive carcinoma present at inked resection margin without broad tumor transection) was present in three cases. The remaining case had widely negative margins (5 mm from invasive carcinoma). The cases and their characteristics are summarized in Table 1.

In 4 out of 10 cases, the virtual 3D specimen map was used to discuss the case before final pathology reporting. In the remaining six cases, the virtual 3D specimen map was available for review by the surgical and pathology teams, but no formal documentation of its use took place.

Data extracted from the final pathology report released in the EMR for each of the cases described above were used to create 10 visual pathology reports. A representative visual pathology report for one of the 10 cases is demonstrated in Fig. 5. The remaining nine cases are included in the supplement (Supplemental Figs. 1–9).

Standard, written pathology reports contained, on average, 6 pages and 850.1 words (describing only the primary tumor and margins, not nodal contents or biopsies). The visual pathology reports communicate the essential information present in the standard written pathology report, with the addition of a visual representation of the 3D structure of the resected specimen and exact anatomic locations of the sampled margins. The visual pathology reports were able to be condensed into a single page for all 10 cases and contained on average 293.4 words. Wilcoxon signed-rank test indicated a significant difference between standard pathology report word count (850.1, SD 213.8) and pathology report of the future word count (293.4, SD 41.4), ($p = 0.002$). These results are summarized in Table 2 and Fig. 6.

Discussion

In this report, we expand upon our previous work detailing 3D scanning and specimen mapping to propose a framework for incorporating virtual 3D specimen maps into multimedia visual pathology reports. This format condenses the traditional several page pathology report with lengthy blocks of descriptive text into an easily digestible format. Each visual pathology report fits on one page and contains information regarding tumor characteristics, gross measurements, final margin status, and pathological staging found in the traditional pathology report, with the addition of a visual representation of the anatomic structure of the specimen and sites of close or positive margins.

Following oncological resection, the operating surgeon and the PA who grosses the specimen are often the only multidisciplinary team members who handle and visualize the resected tumor. There is minimal visual representation available for reference when pathologists are reviewing microscopic slides, pathologists and clinicians are discussing findings for clarification, or when clinicians caring for the patient are independently reading the final written pathology report, which is several days to weeks after surgery. This can lead to inadequate transfer of information between providers, which is one of the most common contributors to medical error according to the Joint Commission.[16] In fact, one study found that surgeons misunderstood final pathology reports 30% of the time and that surgical experience reduced, but did not eliminate this problem.[17] Similarly, studies have found that miscommunication of frozen section results during intraoperative consultation between surgeons and pathologists is common,[18] and that this has the potential to significantly alter intra-or postoperative patient management.[8,18,19] There has been virtually no research to investigate the impact of miscommunication between surgeon and pathologist regarding final margin status or misinterpretation of the final pathology report by the wider multidisciplinary cancer care team. This remains a significantly understudied problem which requires further investigation. Whereas there have been some efforts focused on improving the consistency of final pathology reporting with synoptic summaries, templates, section summaries, and recommended report formatting for optimal comprehension,[8,9] these methods fail to address some of the major issues identified by our team of the potential for miscommunication of written final pathology reports.

The feasibility of 3D scanning and virtual annotation of head and neck cancer specimens to address this issue has been described; however, much of this work has focused on the use of virtually annotated 3D models during intraoperative consultation between surgeon and pathologist.[12,13,20–23] Whereas intraoperative frozen analysis is an important aspect of clinical care, the importance of conveying final pathology results to treating clinicians and patients cannot be understated. For this reason, the protocol of 3D specimen mapping and the idea of visual pathology reports was developed.[10,11] The ability for pathologists and clinicians to clearly visualize the specimen and its pathological

Table 1
Case characteristics for 10 pathology reports of the future.[a]

Case	Sex	Procedure	Anatomic subsite	Histology	pTNM stage	Margin status
1	M	Segmental mandibulectomy, anterior glossectomy	Oral cavity (mucosal lip)	SCCa	T4aN3b	Close[a]
2	M	Left tongue base resection	Oropharynx	SCCa (p16+)	T1N1	Positive
3	M	Left oral cavity composite resection	Oropharynx	SCCa	T4aN0	Close
4	M	Anterior composite resection	Oral cavity (ventral tongue)	SCCa	T3N3b	Close
5	M	Total laryngectomy, partial thyroidectomy	Larynx	Adenosquamous carcinoma	T4aN0	Negative
6	F	Total laryngectomy, partial pharyngectomy	Larynx	SCCa	T4aN0	Close
7	M	Right tongue and mandible composite resection	Oral cavity (floor of mouth)	SCCa	T3N0	Close
8	F	Left buccal resection	Oral cavity (buccal mucosa)	SCCa	T4aN3b	Positive
9	M	Right retromolar trigone composite resection	Oral cavity (retromolar trigone)	SCCa	T4aN1	Positive
10	M	Right oral cavity composite resection	Oral cavity (buccal mucosa)	SCCa	T4aN3b	Close

[a] Close defined as <5 mm from invasive tumor.

13) ORAL CAVITY COMPOSITE RESECTION [MAIN SPECIMEN]
9.3 x 6.8 x 5.5 cm composite resection

Sectioning reveals a 5.5 cm (anterior to posterior) by 5.4 cm (medial to lateral) by 3.4 cm (depth) tan-white, gritty, necrotic mass.

The specimen is inked as follows:
GREEN = POSTERIOR
RED = SUPERIOR
ORANGE = DEEP
BLACK = RIGHT
BLUE = LEFT

Adverse Risk Factors:
PNI – present, focal
LVI – present

Nodal Characteristics:
2 of 81 lymph nodes positive
ENE – present

Greatest dimension: 5.5cm
Depth of invasion: 34mm

Final stage: pT4aN3b

ANTERIOR PARTIAL GLOSSECTOMY, SEGMENTAL MANDIBULECTOMY

MARGIN	SECTION
Right bone margin shave – frozen section NEGATIVE FOR CARCINOMA	A
Left bone margin shave, bisected – frozen section NEGATIVE FOR CARCINOMA	B
	C
Mass invading mandible	D
Left skin and soft tissue margin	E
Right skin and soft tissue margin	F
Mass invades base of tongue 1.7cm to posterior tongue margin 0.8cm to posterior soft tissue margin	G
1.7cm to deep soft tissue margin	H
2.2 cm to left soft tissue margin	I
1.5cm to right soft tissue margin	J
Superior skin and soft tissue	K
Inferior skin and soft tissue	L
Superior mucosal margin CLOSEST TO INVASIVE TUMOR (3mm)	M
Mass invading skin	N
Representative full thickness mass, bisected *(See anterior view)*	O
	P
Additional mass to superior skin and mucosa margin	Q
Representative sublingual gland	R

VIRTUAL 3D SPECIMEN MAP

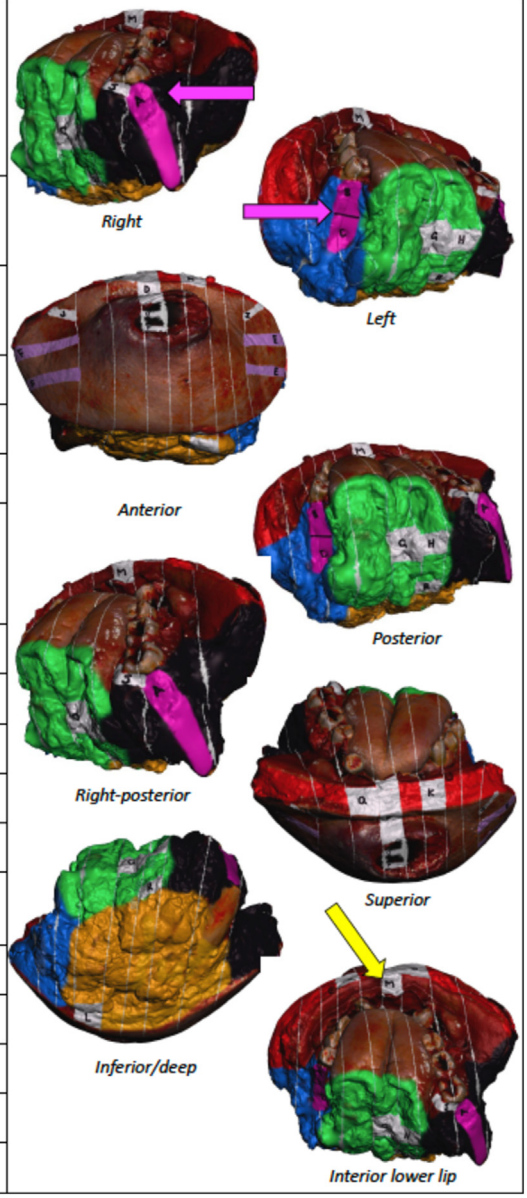

Fig. 5. Pathology report of the future for the case described in the text in Fig. 4. Pink arrows demonstrate the sites of frozen section margin sampling and their subsequent reporting. The yellow arrow demonstrates the close permanent margin identified in section K.

processing for themselves in an interactive format offers unlimited angles of viewing. Given the need for assistance during microscopic slide interpretation and further treatment planning by the multidisciplinary cancer care team, the authors believe that the lack of a visual representation of the anatomic structure and orientation of the resected cancer should be improved upon in the modern era.

Previous investigations within 3D scanning have presented valid limitations to this method including cost, timeliness, and the ability to easily incorporate this method into standard surgical workflow.[24] In an era where staff shortages, high costs of care, and increasing complexity make it more difficult than ever to get work done in an efficient and timely manner, it is reasonable to ask if we are doing anything more than creating aesthetic figures. Over a 4-year period, our lab has worked to minimize these limitations by: (1) utilizing a relatively low cost, commercially available desktop 3D scanner ($2399 USD, hardware and software system) and a standard laptop equipped with a discrete graphics card and series 9 processor,

Table 2
Average page and word count in standard pathology reports *vs* visual pathology report.

Case	Number of pages – Standard	Number of pages – Visual pathology report	Number of words – Standard	Number of words – Visual pathology report
1	9	1	913	279
2	7	1	587	266
3	4	1	663	280
4	6	1	712	223
5	7	1	980	347
6	5	1	979	322
7	6	1	1250	312
8	4	1	649	245
9	5	1	729	318
10	7	1	1039	342
Avg.	6	1	850.1	293.4

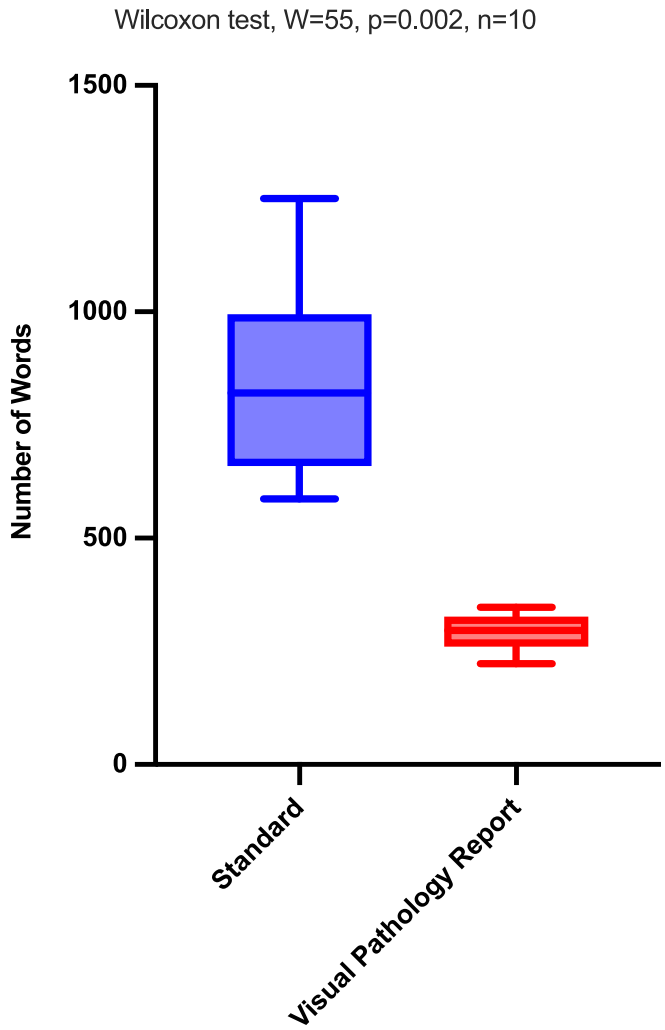

Fig. 6. Comparison of word count between standard pathology reports and visual pathology reports.

(2) creating efficiency in the process with the use of a mobile 3D scanning cart (Fig. 1) that can be positioned outside the operating room (OR) or in the pathology lab, and (3) working to digitally annotate specimens alongside prosectors mirroring their grossing process with minimal if any additional time required. To date, our team has scanned 219 cases. The actual 3D scanning process itself takes an average of 8–10 min.[12] The most time-consuming step of this process is manual alignment, however, the specimen is passed off to the prosector while alignment occurs, therefore no additional time to the gross examination is added during this step, which is of particular importance during intraoperative frozen sections. The additional time added for scanning is deemed acceptable by our team as other portions of the case (i.e., neck dissection, flap harvest, reconstruction) proceed during 3D scanning and time under general anesthesia is not increased. The Mount Sinai group has a similar 3D scanning protocol that focuses primarily on the annotation and communication of intraoperative frozen section using CAD software, demonstrating that these data can be successfully acquired in real time at multiple institutions.[20–23] We both envision that the future of surgeon pathologist communication will include visual models.[25]

In this study, the additional time required for creation and use of a visual pathology report must also be considered. This was performed by a member of our research team retrospectively, and therefore did not add any additional time to clinical care. Future investigations are needed to assess the feasibility of creating visual pathology reports concurrently with the release of the final pathology report and whether this creates any delays in pathological reporting. Given the length of time between surgery and the release of the final pathology report, our team feels confident that visual pathology reports would be able to be created in a reasonable timeframe for release with the final report. Aside from the important considerations of cost, time, and space, the learning curve for this protocol must be considered. The training of a new research team member on this method takes on average 2 weeks. This presents a challenge for the scaling of this protocol to additional services and eventually other institutions. We hope by continuing to demonstrate the utility of this new data source, we will ultimately be able to overcome this barrier with the advancement of both hardware and software. Ideally, this protocol could be performed by the PA or resident who processes the case; however, this will require improvements in existing software. The authors recognize the current staff shortages of both PAs and pathologists and that creating further work for these team members is not sustainable nor advisable. The authors further recognize that it is challenging to measure the utility of a visual pathology report against the status quo without significant investigation into current communication barriers for final pathological reporting. Future, prospective trials are needed to investigate the feasibility of creating visual pathology reports for all locally advanced head and neck cancer cases and demonstrate clinical value.

Future directions for this research include software development for the specific use case of annotating virtual 3D specimen models and the ability for this software to interface with the EMR. One can envision that final reports for other modalities, such as radiological imaging, which also lack visual representation could contain screenshots. It should be feasible to further integrate visual pathology reports into software systems such as PACS, Surgical Information Systems, or Pathology LIS 3D, to more broadly disseminate this new source of data. Additionally, we are actively investigating the impact of visual pathology reports during adjuvant RT treatment planning (NCT# 05743569). Other potential applications of visual pathology reports include their use to enhance multidisciplinary care discussions at tumor board, as adjuncts in medical education, for surgical and pathological quality control in clinical trials, and to increase patient transparency.

Conclusions

In this study, we present a condensed, visual pathology report of the oncological specimen and its pathological processing. The utility of this new source of data has the potential to improve cancer care not only for head and neck cancer patients but also across many solid malignancies. We can envision that the pathology report of the future will integrate standard pathological reporting and visual representation of both the microscopic and 3D structure of the specimen. In the increasingly virtual world, the standard written pathology report lags behind the plethora of information that we could have at our fingertips.

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Declaration of competign interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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