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Research article

Three-dimensional perception of cinematic rendering versus conventional volume rendering using CT and CBCT data of the facial skeleton

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A B S T R A C T

The aim of this exploratory study is to analyse whether three-dimensional cinematic rendering image reconstructions offer advantages over conventional volume rendering in the visualisation of cone beam computed tomography (CBCT) and computed tomography (CT) images of the facial skeleton. This is of interest, as some information gets lost during the rendering process. This especially applies to structures in the background of the image and some surface information which can be lost. The commonly applied two-dimensional representation of CBCT or CT images in three different axes requires experience for interpretation. Cinematic rendering is a new three-dimensional post processing reconstruction technique, creating photo realistic visualisations, thus possibly enabling an easier interpretation of the images.

In this study, ten investigators assessed ten separate patient cases of the orofacial skeleton. For each case, a conventional volume rendering image reconstruction and a cinematic rendering reconstruction of the same area was created. A specially designed questionnaire assessed both objective and subjective criteria of image perception. Objective criteria were assessed by predefined questions on the visual perception of anatomical image characteristics, showing the two reconstruction types of each case randomly to the investigators in two sessions. Subjective criteria were assessed via a visual analogue scale, showing both reconstructions simultaneously in a third session.

The results show that cinematic rendering offers advantages especially in the evaluation of depth perception and three-dimensionality. Volume rendering shows advantages in surface sharpness. Cinematic Rendering was subjectively rated higher for almost all reconstructions. The cinematic rendering process however may cause loss of information and blurring of surfaces compared to volume rendering. With respect to the subjective impression, cinematic rendering scored better than volume rendering. The visualisation is perceived as being very close to reality.

1. Introduction

Three-dimensional (3D) imaging is of great importance in surgical specialties. It allows a realistic understanding of the anatomical situation prior to a surgical intervention. For computed tomography (CT) images, 3D-information is reconstructed from a series of two-dimensional (2D) radiographic images taken around one of the three axes: axial, sagittal, coronal (Abramovitch and Rice, 2014). The interpretation of the anatomical situation requires radiological experience.

In the past years, the technology of 3D-viewers greatly improved. Today volume rendering (VR) is used for the reconstruction of almost real time 3D reconstructions of CT or cone beam CT (CBCT) data (Ibrahim and Al-Rawi, 2018). A new reconstruction technique is

Abbreviations: CT, Computed Tomography; CBCT, Cone Beam Computed Tomography; 3D, Three-dimensional; 2D, Two-dimensional; VR, Volume Rendering; CR, Cinematic Rendering

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Table 1
Image source used for the reconstruction.

Patient case	Image source	Type	Voxel Size	Slice Interval	Slice Thickness	kV
Mandibular fracture	CT	Siemens Somatom definition Flash	535 µm	0.70 mm	0.75 mm	120
Dysgnathia	CT	Siemens Somatom definition AS plus	435 µm	0.50 mm	0.75 mm	100
Buccaly tilted tooth 43 after faild orthodontics	CBCT	Morita Accuitomo	250 µm	0.50 mm	1.00 mm	90
Root resorption of tooth 34	CBCT	Morita Accuitomo	250 µm	0.50 mm	1.00 mm	90
Impacted and curved tooth 15	CBCT	Morita Accuitomo	80 µm	0.56 mm	0.96 mm	90
Cleft lip and palate	CBCT	KaVo 3D eXam	400 µm	0.40 mm	0.40 mm	120
Root fracture of tooth 21	CBCT	Morita Accuitomo	80 µm	0.48 mm	0.96 mm	90
Salivary stone of the sublingual gland	CBCT	Morita Accuitomo	250 µm	0.50 mm	1.00 mm	90
Ameloblastoma	CBCT	Morita Accuitomo	250 µm	0.50 mm	1.00 mm	90
Exostosis	CBCT	Morita Accuitomo	250 µm	0.50 mm	1.00 mm	90

CT = Computed Tomography; CBCT = Cone Beam Computed Tomography.

called cinematic rendering (CR). Both reconstruction methods (VR, CR) are based on the post-processing of DICOM data. Thus, no new imaging acquisition is required (Eid et al., 2017; Elshafei et al., 2019).

The rendering technique behind CR was inspired by techniques used for the production of computer-animated movies in the movie industry (Hieslmair, 2015; Desiderio and Phillips, 2019).

It has been introduced for radiological application and is increasingly used in medical imaging. New areas of applications are constantly developed (Ebert et al., 2017; Radic et al., 2018; Stadlinger et al., 2019; Wollschlaeger et al., 2020). CR is based on the further development of VR and uses a complex algorithm, simulating the simultaneous impact of billions of light beams from all directions. Thus, a photorealistic reconstruction is created (Dappa et al., 2016). Like VR, these 3D reconstructions facilitate the assessment of anatomical structures (Binder et al., 2019).

Previous studies showed that CR is helpful for understanding complex anatomical structures. It has been attributed a particular advantage in student and patient education (Ebert et al., 2017; Röschl et al., 2019; Binder et al., 2020). Until now, the impact of CR on the visualisation of the facial skeleton has rarely been analysed. We showed the CR reconstruction of CBCT images in 2D-views (Stadlinger et al., 2019, 2021). The aim of this exploratory study was to investigate in a 3D rotational reconstruction whether CR offers an advantage in the visualisation of CBCT or CT reconstructions compared to VR and thus will facilitate the clinical routine in near future. For this purpose, two endpoints were defined: The i) 'objective' correctness of interpretation and ii) the 'subjective' perception. The two endpoints were assessed in different sessions, and with different metrics i) in a cross-over design and with correct/incorrect answers and ii) in an individual session on VAS scales. In contrast to other studies, that mostly compare static images, a 3D rotational reconstruction was created.

2. Material and methods

2.1. Patient cases and reconstructions

For the comparison of CR and VR reconstructions, ten different anatomical conditions/pathologies of the facial skeleton from ten different patients were selected. Selection criteria was a case mix, providing a broad representation of conditions or pathologies of the orofacial area. Table 1 shows the imaging source (CT or CBCT). Two preliminary studies showed the technical feasibility of CR reconstructions and qualitative assessment in 2D views (Stadlinger et al., 2019, 2021). The present study created 360° rotatable CR and VR reconstructions in order to enable a score assessment of 3D images. For this purpose, six cases previously solely reconstructed in 2D planes (Stadlinger et al., 2019, 2021) and four additional cases were 360° 3D computed and analysed by ten investigators, using a predefined score based on visual image characteristics. Study inclusion criteria was the patients` consent on the use of imaging data for research. The imaging data was anonymised with regard to patient related data.

2.2. Study design and investigators

Ten investigators were recruited for this exploratory study. All investigators were dentists with several years of professional experience, being employed at the Clinic of Cranio-Maxillofacial and Oral Surgery, University of Zurich/University Hospital Zurich (Table 2).

All investigators were experienced in assessing 3D images. They were informed on the aim of the study, being the comparison of two different types of reconstruction (VR/CR). Every investigator individually assessed the same ten cases using a standardised questionnaire. A coordinator (TS) explained the viewer software and presented the images to the investigators. For data collection, a period of three weeks was defined, allowing three assessment sessions and a one-week wash-out period in between.

During the first two sessions of the experiment, the investigators were randomly shown either a VR or a CR reconstruction of the same patient case. In the third session, both images were shown simultaneously, allowing the direct comparison of the two reconstruction methods. For this third, comparative assessment, a new questionnaire was applied.

Standardised questionnaires were developed by two attending physicians (BS, SW) and TS, addressing the ten cases. The questions addressed anatomical image characteristics of each case according to certain visual parameters: depth perception, surface sharpness, three-dimensionality, positional relationship, form perception, contrast and photo-realism. This categorisation served to standardise the comparison between VR and CR. Table 3.

2.3. Data assessment and questionnaire

The questions for the ten investigators were grouped into objective questions, as asked in session 1 and 2 and subjective questions as asked in session 3. The applied questionnaires asked five questions per case and used two types of questions (objective/

Table 2
Characteristics of participants.

Participant	Sex	Age	Work experience (years)	Department
1	Female	33	6	OS
2	Female	29	5	OS
3	Female	26	2	OS
4	Female	29	5	OS
5	Male	30	3	OS
6	Male	29	2	OS
7	Male	31	5	OS
8	Female	31	7	OS
9	Female	25	1	CMS
10	Male	38	10	CMS

f = female; m = male; OS = Oral Surgery; CMS = Cranio-Maxillofacial Surgery.

Table 3
Patient cases with corresponding visual image characteristics.

Patient case	Patient case number	Visual image characteristics for objective questions	Visual image characteristics for subjective questions
Mandibular fracture	1	Depth perception, three-dimensionality	Positional relationship, form perception, photo-realism
Dysgnathia	2	Positional relationship, positional relationship	Three-dimensionality, surface sharpness, photo-realism
Buccaly tilted tooth 43 after faild orthodontics	3	Contrast, contrast	Form perception, three-dimensionality, photo-realism
Root resorption of tooth 34	4	Three-dimensionality, depth perception	Depth perception, contrast, photo-realism
Impacted and curved tooth 15	5	Surface sharpness, positional relationship	Form perception, surface sharpness, photo-realism
Cleft lip and palate	6	Surface sharpness, three-dimensionality	Positional relationship, depth perception, photo-realism
Root fracture of tooth 21	7	Form perception, depth perception	Contrast, contrast, photo-realism
Salivary stone of the sublingual gland	8	Three-dimensionality, surface sharpness	Positional relationship, depth perception, photo-realism
Ameloblastoma	9	Depth perception, Contrast	Positional relationship, Surface sharpness, photo-realism
Exostosis	10	Form perception, form perception	Three-dimensionality, surface sharpness, photo-realism

All patient cases are listed with their corresponding image characteristics.

subjective). A list of the questions can be found in Supplement 1. Objective questions made a distinction between correct/incorrect answers. An example is the following: "What do you notice on the vestibular surface of tooth 34″. Prior to the evaluation of the questionnaires by the investigators, a gold standard (correct answers) was determined by two attending physicians (BS, SW) and the coordinator of the investigation (TS). To determine a gold standard, the original CT or CBCT data sets in the three axial planes (coronal, axial, sagittal) were analysed together with the 3D reconstruction. For each objective question asked, correct answers and answer ranges were predefined based on 2D and 3D images, prior to the assessment of the investigators. Answers were given in written text. In case of fuzzy answers, the coordinator and the attending physicians considered the correctness of the answers according to Supplement 1.

During the third session of image assessment, VR and CR were presented to the investigators at the same time on one screen. Here, subjective questions were asked and requested a mark on a visual analogue scale from 0 to 10. An example is the following: "How realistic do you rate the image shown?" A score of "0" would be unrealistic, a score of "10″ photorealistic. Each question targeted one of the earlier mentioned visual image characteristics.

To ensure identical settings and equal instructions each investigator had to answer all questions in the given order without the possibility to return to a previous question. This was supervised by TS. The first two sessions consisted of 20 questions each. In session three, there was a total of 30 questions.

2.4. Cinematic and volume rendering: technical details

VR as well as CR reconstructions were both generated from the same DICOM data. The CR prototype software (Cinematic Rendering Version 1.5.5, syngo.via Frontier, Version VB 30, Siemens Healthineers, Forchheim, Germany) was used.

It is known that the quality of the reconstruction depended on the quality of the DICOM data (Elshafei et al., 2019). Unprocessed, anonymised DICOM data from a CT or CBCT was uploaded into the software. Predefined settings for different anatomical regions were used. Manual adjustment of all settings (individual windowing and adjustment) was applied.

VR images were reconstructed using the standard clinical post-processing software of the Department of Neuroradiology (Agfa HealthCare, IMPAX PACS, Agfa Belgium).

For each of the ten cases, 360° rotatable CR and VR reconstructions were performed in steps of 10–20°, enabling an equal comparison. Fig. 1 illustrates 18 images in different angles, serving to achieve a 360° perception of every case. Due to the high amount of data, it was not possible to add a reconstruction for every degree of rotation.

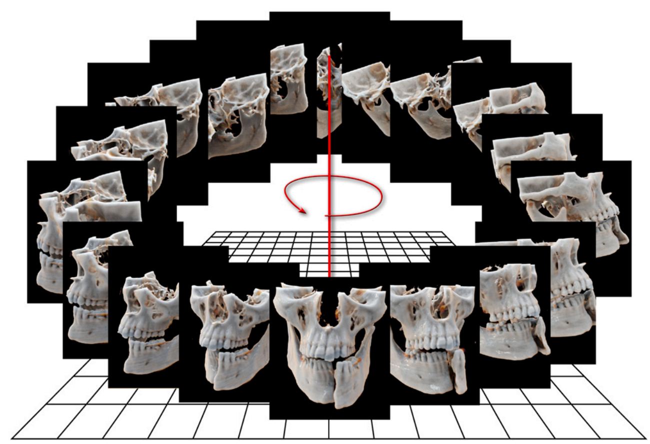


Fig. 1. Single images in different angles, enabling a 360° case presentation.

VR and CR reconstructions were presented to the investigators using the JiveX DICOM viewer (Visus Health, Bochum, Germany). The assessment always took place in the same room under equal conditions, using a diagnostic monitor (NEC, MDview 243).

2.5. Statistical analysis

Graphics and descriptive statistics were computed during data exploration and individual models were fitted for each endpoint.

The objective endpoint with the correct/incorrect answers was modelled using a mixed-effects logistic regression while the subjective endpoint with the VAS response was modelled with an ordinary mixed-effects regression. Both models were specified with the fixed explanatory variables image reconstruction (CR or VR), visual image characteristics (depth perception, surface sharpness, three-dimensionality, positional relationship, form perception, contrast and photo-realism) and their interaction. Random intercepts were included for the investigators and the potential interactions of the explanatory variables. Model simplification was performed using Likelihood Ratio Tests (Zuur et al., 2009). Simplified models were thoroughly checked for model assumptions using residual analyses. Following this, pairwise comparisons were conducted on the

Table 4
Total number of right or false answers for the rendering methods CR vs. VR of the first two sessions.

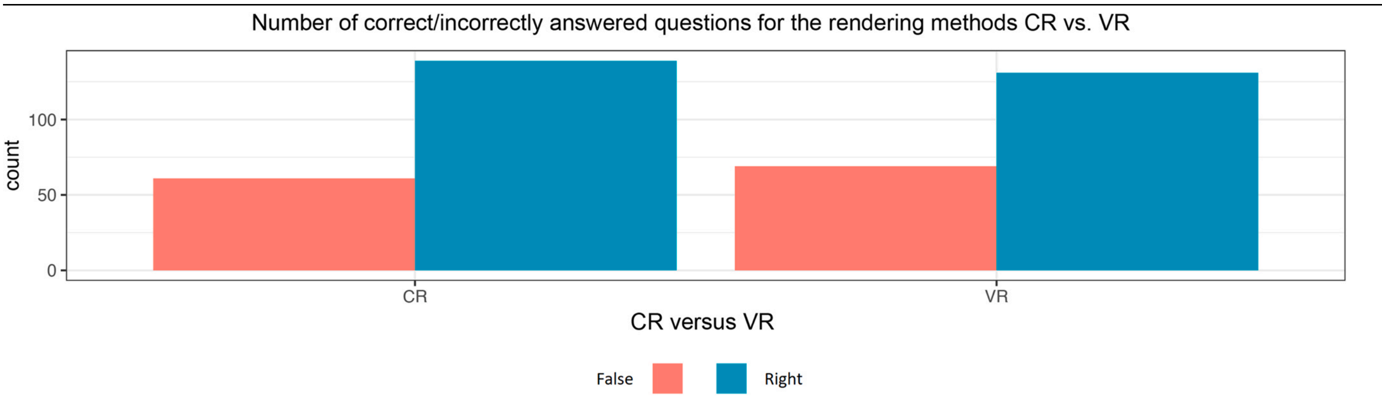
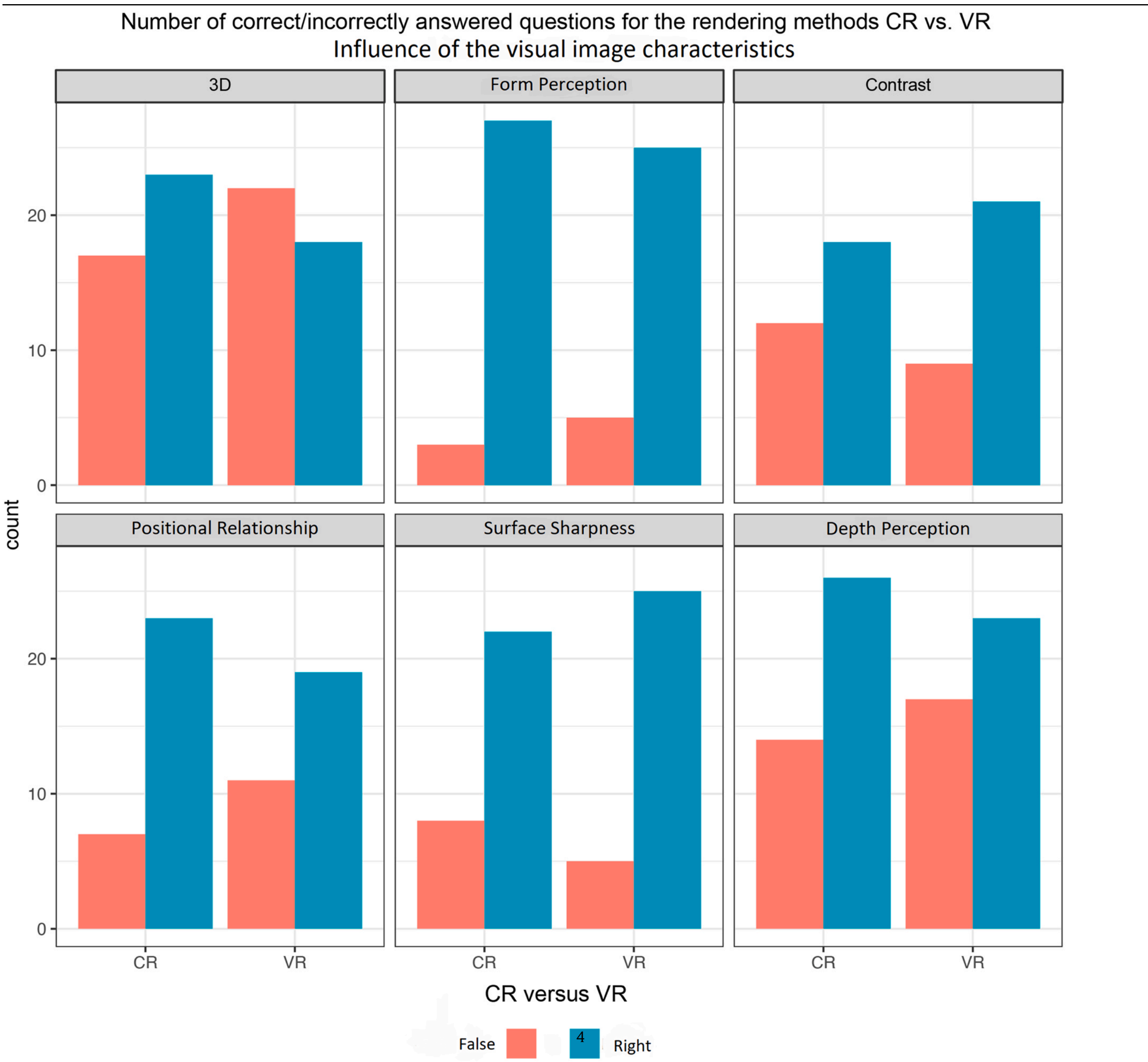


Table 5
Total number of right or false answers for the rendering methods CR vs. VR, analysed by the visual image characteristics of the first two sessions.



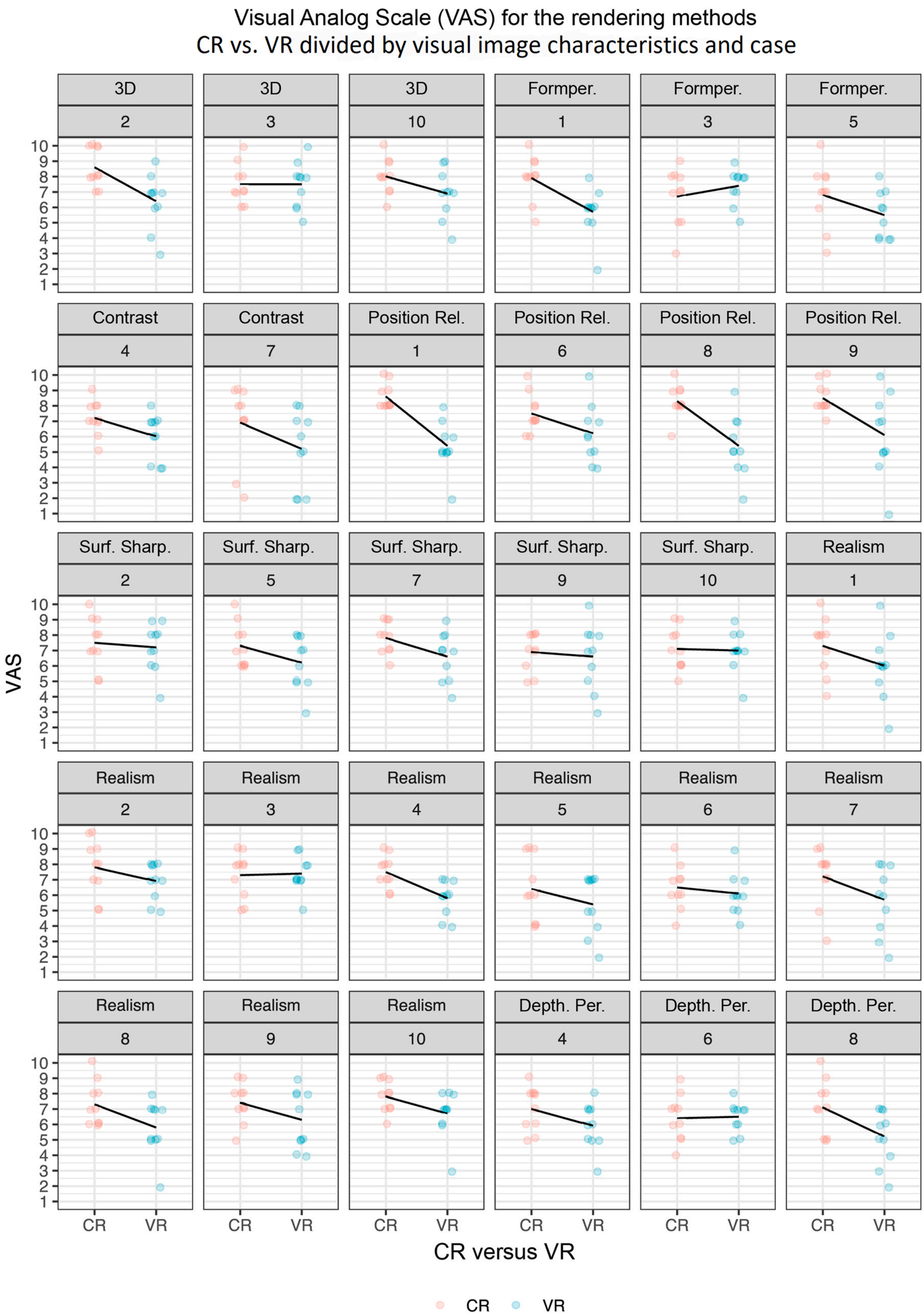


Fig. 2. Visual Analog Scale for the rendering methods CR vs. VR in the third session. Data is sorted by visual image characteristic and patient case numbers (below visual characteristics).3D = Three-Dimensionality; Formper. = Form perception; Pos. Rel. = Positional Relationship; Surf. Sharp. = Surface Sharpness; Depth. Per. = Depth Perception; Realism = photo-realism.

Fig. 3. Cinematic rendering reconstruction of an exostosis of the right mandibular corpus, oblique – lateral (a) and frontal (b) view. Volume rendering reconstruction the same data set, oblique – lateral (c) and frontal (d) view.

remaining terms in the simplified models, further investigating the significant influence of the image reconstruction, visual image characteristics and their interaction in the case of the subjective endpoint (the objective endpoint did not show a significant difference between the image reconstructions but only between the visual parameters). The p-values resulting from the pairwise comparisons were adjusted for multiple testing according to Tukey.

All statistical analyses and plots were performed using the statistical software R (R Foundation Statistical Computing, Vienna, Austria) (R Core Team, 2015), including the packages lme4 (Bates et al., 2019), lmerTest (Kuznetsova et al., 2017), car (Weisberg and Sanford, 2019), emmeans (Russel, 2021), ggplot2 (Wickham, 2016), and DHARMa (Hartig, 2021).

3. Results

3.1. Objective endpoint

Overall, the majority of questions were answered correctly, regardless of the reconstruction method. In the CR group, there were 69.5% correct and 30.5% incorrect answers. In the VR group, there were 65.5% correct and 34.5% incorrect answers (Table 4). Consequently, no significant difference could be found between the image reconstruction methods with regard to the correctness of the image interpretation.

However, the correctness of both reconstruction methods depended strongly on what visual image characteristic was assessed as shown in (Table 5). The chance of giving correct answers to questions on specific image characteristics was largely different between the pairs three-dimensionality – form perception (Odds 1.1 vs. Odds 6.5 $p < 0.001$), three-dimensionality – surface sharpness (Odds 1.1 vs. Odds 3.6 $p = 0.017$) and form perception – depth perception (Odds 6.5 vs. Odds 1.6 p- = 0.018). All other specific questions on image characteristics showed no significant differences between the pairs.

Besides these strong and significant contrasts, descriptive statistics showed that more correct answers were received from CR reconstructions in four out of six visual image characteristics. For the visual parameter three dimensionality, CR scored 57.5% correct answers versus 45.0% in VR. Form perception: CR 90.0% versus VR 83.3%. Positional relationship: CR 76.7% versus VR 63.3%. Depth perception: CR 65.0% versus VR 57.5%. Descriptive statistics further showed that two image parameters scored better in VR reconstructions. For the parameter contrast, VR scored 70.0% correct answers while CR scored 60.0%. Surface sharpness: VR 83.3% versus CR 73.3%.

3.2. Subjective endpoint

For almost every single question and visual image characteristic, the investigators rated the presentation of CR higher compared to VR. Fig. 2 illustrates the visual analogue scale (VAS) scorings for both rendering types (CR and VR) sorted by visual image characteristic and patient case number. The single diagrams show the answers to each question by investigator and a trend line. Significant differences

Fig. 4. Tilted tooth 43 post failed orthodontic treatment. a, b: Cinematic rendering reconstruction. Oblique view (a) of the mandibular corpus and cranio-caudal view (b) of the lingual arch. c, d: Volume rendering reconstruction. Oblique view (c) of the mandibular corpus and cranio-caudal view (d) of the lingual arch.

in subjective ratings between CR and VR were found in the following visual characteristics:

- Three-Dimensionality ($p = 0.024$), VAS estimated mean of 8.03 for CR versus 6.93 for VR.
- Contrast ($p = 0.007$), VAS estimated mean of 7.05 for CR versus 5.60 for VR.
- Positional relationship ($p < 0.001$), VAS estimated mean of 8.22 for CR versus 5.78 for VR.
- Photo-realism ($p = 0.015$), VAS estimated mean of 7.25 for CR versus 6.21 for VR.
- Depth perception ($p = 0.046$), VAS estimated mean of 6.83 for CR versus 5.87 for VR.

The visual characteristics form perception and surface sharpness showed no significant differences with respect to VAS scoring.

4. Discussion

The aim of this study was to investigate whether CR is superior to VR in the visualisation of 3D-CBCT or CT reconstructions of the facial skeleton. To obtain accurate information, different visual image characteristics and two endpoints of the assessment were defined, being the 'objective' correctness of interpretation and the 'subjective' perception. These two endpoints were assessed in different sessions.

The visual perception of the 3D reconstructions was analysed with regard to different visual characteristics. The criteria to define these visual characteristics were partially adapted on criteria as described by Preim et al. (2016). *Depth perception* describes the ability to perceive spatial depth. It enables the observer to estimate distances between objects lying behind each other (Pfautz, 2002). *Surface sharpness* is assessed for the evaluation of surface structures. It provides information on the differentiation of details. *Three-Dimensionality* describes the spatial representation of objects within the three axes. Effects like shadow lines and reflection zones can be added (Preim et al., 2016). The orientation of an object in relation to its surrounding space is referred to as *positional relationship*. A clinical example is the angulation of a retained third molar and its relation to structures like the inferior alveolar nerve. The *perception of form* describes the perception of the internal geometry of figures and objects. This process happens subconsciously, while our brain sees an object and assigns a form to it (Fantz, 1961). *Contrast* is a feature to distinguish the brightness curve of an image or between two pixels. An object needs to have a sufficiently high contrast to its surroundings in order to be perceived (Preim et al., 2016). The image characteristic photo-*realism* analyses how realistically an object is perceived on screen. Questions on the latter image characteristic were solely asked in the third session and implied a purely subjective assessment.

Questions on the mentioned visual image characteristics were integrated in the questionnaire for the selected ten cases. Thus, an overview on the pros and cons of CR visualisation of different pathologies in the orofacial area in comparison to VR could be gained.

4.1. Objective endpoint

The results of the objective endpoint showed that significant differences were found for the chance to answer questions on image characteristics correctly. This was the case for comparing *three-dimensionality* to *surface sharpness* and *form perception* as well as comparing the latter to *depth perception*. It was not the case for the other pairs of visual image characteristics. Descriptive statistics showed that CR scored higher in *depth perception* compared to VR. This observation can be illustrated by Fig. 3a, showing shadows and reflections, giving a strong impression of spatial depth. The exostotic growth of the neoplasia out of the cortical bone can be better perceived in CR compared to VR. Fig. 3b shows the VR reconstruction, suggesting a sharper surface structure. Analysing the aspect of *three-dimensionality*, CR also scored higher. In Fig. 4a and b, three-dimensionality is better perceived due to CR reconstruction. In the cranial-caudal view of the central mandible, the lingual arch with its decent in caudal direction is clearly visible in CR. This is not as visible in VR reconstruction. Fig. 4c and d show a sharper *surface structure* using VR. Since VR and CR use different lighting models, they give a different impression of depth (Rowe et al., 2018). VR simulates only one direction of light rays per voxel, creating the same shadow cast on the whole image. CR creates countless light rays per voxel and even simulates their reflection on neighbouring structures. This leads to complex shadows and reflections as they would occur in natural light (Dappa et al., 2016). This complex process necessitates high computer processing power (Pfautz, 2002). Lacking this shadow effect, objects lying in front of each other appear to have almost no inter-object distance even in case of larger gaps.

When investigating the visual image characteristic *form perception*, both CR and VR showed high scores. Two questions asked for the description of an object`s form. Here, all investigators scored full points for both reconstruction techniques. It seems that the shape of an object is equally well visualised in both reconstruction techniques. As a limitation, it should be mentioned that these two questions did not go into details of form perception, limiting its general validity.

CR also showed an advantage over VR when examining the representation of the *positional relationship*. Due to the increased three-dimensional representation of CR, it also depicts the position and orientation of shown structures more realistically compared to VR.

Looking at the *surface sharpness*, VR showed more correct answers than CR. One of the reasons is the rather plastic presentation of CR reconstructions. The rendering results in a blurring on the surface. Here surface sharpness gets lost in CR.

Contrasts were also better represented using VR. Reason may be the same as for the surface sharpness. Due to the blurring of some surface structures, CR does not map differences between two adjacent pixels in detail. Neighbouring pixels seem to merge.

4.2. Subjective endpoint

In most subjective categories, CR gave higher scores in the VAS scale compared to VR. This difference was significant for the visual parameters *three-dimensionality*, *contrast, positional relationship, photo-realism and depth perception*. In this third session, investigators were allowed to see both reconstructions methods, CR and VR of the same object simultaneously. This subjective assessment asked questions like e.g. "How close to reality do you rate the pictures shown?". CR reconstructions were evaluated to be *closer to photo-realism* compared to VR reconstructions in every patient case. Interestingly, almost all investigators answered this question in the same way. Reason may be, that due to the shadow zones and reflections created, the CR reconstructions appear more three-dimensional (Rowe et al., 2020). Combining these properties with the blurring of the background surface it creates an image that is perceived as close to reality. A side effect seems to be a reduced surface sharpness, as shown by the results of the objects assessment, being in favour of VR for this image characteristic. These subjective questions may be of limited clinical impact, compared to 2D cross-sectional planes. Nevertheless, they show which reconstruction method attracted the viewers more. This may explain the higher level of familiarity, perceived by CR.

Comparable to the literature, our results show that CR improves the perception of depth and enhances the three-dimensional impression of the orofacial skeleton (Caton et al., 2020). Thus, a photorealistic impression is created (Fellner, 2016; Preim et al., 2016; Eid et al., 2017). Possibly, the advantage of CR over VR is even more pronounced when comparing static images. Reason may be, that the examiner needs to extract all information from the depth perception of a single image. With rotating reconstructions, such as used here, the examiner can change the view in order to recognise the three-dimensionality. This however mirrors the clinical situation, where entire rotatable 3D data sets are usually considered. The rotatability of the reconstructions nonetheless also implies a limitation. In some cases, it was not possible to display all reconstructions angled in the exact same way, which may be a limitation. Due to a few degrees of deviation, potentially important structures could be partially hidden. The reason for this discrepancy could be that the reconstructions were made manually and that two different programs were used for the CR and VRT reconstructions. A possible future solution would be standardised and automated reconstructions using one and the same software for both reconstructions.

An advantage of this study is that predefined visual image characteristics were analysed. This facilitates to track the image characteristics, where CR or VR benefits most. Most studies analysing CR do not differentiate the various visual characteristics (Fantz, 1961; Fellner, 2016; Elshafei et al., 2019). The different visual image characteristics allow a precise comparison of the two reconstruction techniques. Thus, conclusions can be drawn when to use CR and when to use VR for clinical assessment.

The 360° CR reconstruction of 10 patient cases involved a serious amount of work, also illustrating that this technique is not yet compatible to every day's use. A possible limitation were the different resolutions of the CTs and CBCTs being included. As the comparison targeted CR versus VR of the same cases and no comparison between the different cases, this aspect is of limited impact. Another limitation could be the lack of comparison to multiplanar reconstructions, considering an underlying ground truth in this data. This however was not the purpose of this study, as we did not assess the diagnostic accuracy of the entire DICOM dataset but solely of the pros and cons of two different methods of volumetric rendering visualisation. This comparison focuses on the strongholds and weaknesses of each reconstruction method. CR gives a strong impression of three-dimensionality and can thus help to better understand complex anatomical situations. It is this visualisation, which the surgeon will have in mind when entering the operating theatre (Mischkowski et al., 2006; Wang et al., 2012). CR as well as VR are valid additions to the multiplanar view. However, multiplanar assessment will remain the gold standard for diagnostic purposes. Additional studies will assess the exact diagnostic value of 3D rotational CR reconstructions with respect to the demonstrated potential advantages and disadvantages.

5. Conclusion

In summary, the results of this exploratory study show, that the application of CR in CT and CBCT data of the facial skeleton shows great potential in parameters like depth perception and three-dimensionality. VR shows high potential in parameters like surface sharpness and contrast. In order to get a first 3D-impression of a pathology, CR seem highly suitable. Therefore, we see CR as a tool to give additive value to conventional VR reconstructions. Assessing conventional multiplanar CT imaging together with CR and VR reconstructions would give additional, valuable visual information for the surgeon.

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Ethical statement

Consulting the Cantonal Ethics Commission, the project did not fall under the Human Research Act and therefore did not require approval for the local ethics committee (Req-2020-00246).

Patient consent

Prior to the radiological examination, each patient agreed to the further use of their data for research purposes by an informed consent.

CRediT authorship contribution statement

Tobias Steffen: Methodology, Conceptualization, Validation, Investigation, Writing – original draft, Writing – review & editing. **Sebastian Winklhofer:** Conceptualization, Software, Validation, Resources, Writing – review & editing. **Felicitas Starz:** Methodology, Conceptualization, Supervision. **Daniel Wiedemeier:** Formal analysis, Data Curation, Writing – review & editing, Visualization. **Uzeyir Ahmadli:** Conceptualization, Software, Resources. **Bernd Stadlinger:** Methodology, Conceptualization, Validation, Supervision, Project administration, Investigation, Writing – original draft, Writing – review & editing.

Declaration of Competing 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 paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.aanat.2022.151905.

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