3D MR SIALOGRAPHY AS A TOOL TO INVESTIGATE RADIATION-INDUCED XEROSTOMIA: FEASIBILITY STUDY

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Purpose: To evaluate whether magnetic-resonance (MR) sialography can be used to investigate radiation-induced xerostomia. Preradiotherapy (pre-RT) and postradiotherapy (post-RT) MR sialographic images of the major salivary ducts (parotid and submandibular) were compared.

Methods and Materials: Magnetic-resonance sialography was performed pre-RT, and 6 weeks and 6 months post-RT on 9 patients with T1-4N0-2M0 naso- or oropharyngeal tumors, on a 1.5-T MR scanner. Patients were positioned in the scanner, using a radiotherapy immobilization mask. Image registration of the MR sialograms pre- and post-RT with each other and with the CT and consequently the dose distribution was performed. A categorical scoring system was used to compare the visibility of ducts pre-RT and post-RT.

Results: Good-quality MR sialographic images were obtained, and image registration was successful in all cases. The visibility score of the parotid ducts and submandibular ducts was reduced at 6 weeks post-RT, which means that the full trajectory of the salivary ducts, from the intraglandular space to the mouth cavity, was only partially visualized. For some of the parotid ducts, the visibility score improved at 6 months post-RT, but not for the submandibular ducts. The mean dose for the parotid glands was 35 Gy (standard deviation [SD] 3 Gy), and for the submandibular glands it was 62 Gy (SD, 8 Gy).

Conclusion: Three-dimensional MR sialography is a promising approach for investigating xerostomia, because radiation-induced changes to the saliva content of the ducts can be visualized. © 2007 Elsevier Inc.

INTRODUCTION

Salivary dysfunction is a prevalent side effect suffered by patients receiving head-and-neck radiotherapy (RT). Lack of saliva production results in impaired quality of life, and can be permanent (1–6). The elucidation of the exact mechanism of radiation damage to the salivary glands has been the subject of many studies (7). It was suggested that damage to the acinar and ductal systems is the main cause of salivary-gland dysfunction in humans after RT (8). It was also suggested that edematous stenosis of the major salivary ducts takes place progressively during irradiation, leading to symptoms of acute sialadenitis with an excretory obstacle (9). In these studies, either changes in saliva and serum electrolyte levels were investigated, or salivary-gland scintigraphy with $^{99m}$Tc-pertechnetate was performed. However, neither these nor other studies systematically investigated the salivary-duct system in humans after RT. In this pilot study, we aimed to do that, by using a noninvasive, novel imaging approach, magnetic-resonance (MR) sialography, for the first time.

Magnetic-resonance sialography is an imaging technique whereby static fluids or slowly flowing fluids in the body, such as saliva, are imaged as high-signal-intensity bright structures against a dark background (10). In other words, the salivary ducts can be imaged because they contain saliva. Saliva itself is the contrast medium. This property alone makes MR sialography an attractive method to use when studying hyposalivation, as in cases of radiation-induced xerostomia. Magnetic-resonance sialography was already proven to be a useful imaging technique for other salivary-gland and duct disorders such as sialolithiasis and Sjögren’s syndrome (11–15).

The conventional method of visualizing the ductal system is by X-ray sialography. This two-dimensional (2D) technique requires injection of contrast medium and manual
skills for cannulation of the ducts, with a risk of failure in case the opening of the ducts cannot be clearly seen (13). That might very well be the case after RT, and especially after surgery. Moreover, it can only be performed on one salivary duct at the time, and the salivary-gland tissue itself is not visible. On the other hand, MR sialography is a three-dimensional (3D) imaging modality, and consequently both pairs of parotid ducts and the submandibular ducts can be imaged simultaneously (16).

Furthermore, 3D MR sialography has the potential to provide spatial information on salivary (dys)function. This information could be beneficial if a correlation is established between the 3D dose distribution and the salivary (dys)function, because it could result in more efficient intensity-modulated radiation therapy (IMRT) treatment planning (17–20). Using conventional RT techniques, the salivary glands are mostly included in full in the irradiation fields, and receive homogeneous doses (17). With IMRT, however, dose painting is possible, and so it is important to investigate whether there is regional radiosensitivity in the human salivary glands and salivary ducts with regard to function, as observed by Konings et al. in animals (21–23). Konings et al. concluded that after partial irradiation of the rat parotid gland, injury to the major excretory ducts and supply routes for blood and nerves in the irradiated lobe could result in late-function loss in the shielded lobe (22).

In a previous study, we developed and evaluated a 3D MR sialography protocol in healthy volunteers, that provided good-quality 3D images of the submandibular and parotid duct systems in a single scan. Moreover, we showed that MR sialograms of the same individual, recorded at different moments in time, are reproducible (16). In this feasibility study, patients receiving RT for head-and-neck tumors were scanned with this 3D MR sialography protocol pre-RT, and 6 weeks and 6 months post-RT. Salivary-flow measurements were performed at the same time intervals as MR sialography.

The primary goal of the present study was to evaluate whether MR sialography could detect changes in the salivary-duct system post-RT compared with the salivary-duct system pre-RT, and could consequently be used as a new tool to investigate radiation-induced xerostomia. Furthermore, the image registration of the MR sialograms pre- and post-RT with each other and with the 3D dose distribution was evaluated.

METHODS AND MATERIALS

Nine patients, treated with primary (7 patients) or postoperative (2 patients) irradiation for T1-4N0-2M0 nasopharyngeal or oropharyngeal cancer, were included in the study. Seven patients were treated with IMRT, and two were treated with 3D-conformal RT (3D-CRT) (17). In cases of 3D-CRT planning, the prescribed dose to the planning target volume (PTV) of the primary tumor and the positive lymph nodes was 70 Gy, and to the elective lymph nodes, 46–50 Gy. The PTV was determined by adding a 5-mm margin to the clinical target volumes (CTVs). The dose was delivered in 35 fractions, and the dose calculation was performed using a commercial treatment-planning system, PLATO RTS, version 2.6 (Nucletron BV, Veenendaal, The Netherlands).

The IMRT planning was performed using the inverse treatment-planning module PLATO-ITP, version 1.1 (Nucletron BV). The dose prescription to the tumor PTV and positive lymph node PTV was 66–69 Gy, and to the elective lymph node PTV, 54 Gy. The total dose was delivered in 30 fractions. The dose constraint to the spinal cord and brain was 30 Gy, with a relatively high penalty. Because of the 5-mm PTV margin, parts of the parotid glands overlapped with the PTVs. At this overlapping volume, the dose prescription of the PTV was used in the optimization process. To the rest of the parotid glands, a dose constraint of 20 Gy with a relatively low penalty was given. The submandibular glands were not included in the optimization process.

Magnetic-resonance sialography was performed on a 1.5-T system (Intera, Philips Medical Systems, Best, The Netherlands). Patients were positioned in the MR scanner with the five-point RT immobilization mask, in the RT treatment position, by the RT technologist. A two-element circular surface coil (FLEX L, Philips Medical Systems, Best, The Netherlands; opening diameter, 170 mm) was placed bilaterally on the RT immobilization mask (Fig. 1). There was a twofold reason for doing this: (1) the standard head-and-neck coil does not permit the use of the immobilization mask; and (2) more importantly, the contrast-to-noise ratio of the parotid duct to fat is higher when using the surface coils than the head coil (16). A 3D water-selective turbo spin echo pulse sequence, with repetition time/echo time (TR/TE) 6,000 ms/190 ms was applied, as described in detail in a previous study (16). The acquired image resolution was 0.8 × 1.4 × 1.5 mm³, and the reconstructed image resolution was 0.4 × 0.4 × 1.5 mm³. Magnetic-resonance sialography was performed pre-RT, on the same day as the planning CT, and was repeated 6 weeks and 6 months post-RT. The scan time was 8–10 min, depending on the size of the scan volume.

Before each MR follow-up session, it was verified in the mold room whether the RT immobilization mask still fit the patient, and consequently whether the pre-RT position was reproducible.

The scan volume included the parotid glands and the submandibular glands bilaterally, and was slightly tilted (5–8°) around the right–left axis. It also included a small tube filled with 25 mL

![Fig. 1. Positioning of the patient in the magnetic resonance (MR) scanner. The surface coils (FLEX L) are placed bilaterally on the radiotherapy (RT) immobilization mask.](image-url)
MnCl₂ · 4H₂O solution, 19.2 mL/L, which was taped onto the immobilization mask at the level of the parotid gland. The signal intensity of that solution was used for normalization purposes when comparing MR sialograms.

The analysis of 3D data sets was performed with in-house-developed software that allows visualization of the transversal, coronal, and sagittal views of the data set together. Thus, any selected point of the data set was viewed in 3D. The trajectory of submandibular (Wharton’s) ducts and parotid (Stensen’s) ducts were mainly visible on the transversal planes, and the higher-order, small parotid-duct branches were more visible on the sagittal planes (16).

A categorical scoring system was used to evaluate the visibility of the salivary ducts (Fig. 2). In brief, the parotid ducts were divided into four parts: two intraglandular (part 1, main duct; part 2, higher-order, small-duct branches), and two extraglandular (part 3, segment of Stensen’s duct superficially to the masseter muscle; part 4, last segment of Stensen’s duct that turns 90° to pierce the buccinator muscle before opening to the oral cavity). The submandibular ducts were divided into two parts (part 1, intraglandular duct and the posterior bend of Wharton’s duct around the posterior edge of the mylohyoid muscle; part 2, the extraglandular segment that runs through the sublingual space and opens to the anterior floor of the mouth near the lingual frenula). The score was 1 if the part was visible, and 0 if it was not. If the whole trajectory of Stensen’s duct (including the small, intraglandular duct branches) was visible, the total score was 4 for the parotid ducts.

For the submandibular duct, the total score was 2 if the whole trajectory of Wharton’s duct and the intraglandular part of the duct were visible. Visibility was scored for each MR sialogram by two observers, and a consensus was reached. This score was used to compare the visibility of ducts post-RT to their visibility pre-RT, and to quantify indirectly whether all or only part of the duct trajectory was detectable.

The MR sialograms 6 weeks and 6 months post-RT, and the planning CT, were registered to the MR sialogram pre-RT, using a mutual information algorithm. The registration was inspected visually using a “linked cursor” approach. Two windows with the registered data sets were simultaneously opened. When the location of a point in one data set was selected, a visible mark was positioned automatically at the corresponding location in the registered data set (24). The registration was considered good when there was a successful match of the body contour, base of the skull, brain tissue, and other recognizable structures, such as blood vessels. Afterwards, the matching of the location of the salivary ducts on the registered MR sialograms was checked, and the 3D dose distribution was superimposed on the sialogram pre-RT. The mean dose to the salivary glands and the mean dose to the salivary-duct parts were also obtained.

The diameters of Stensen’s and Wharton’s ducts upon entry to the glands were recorded. The diameter of the duct was defined as the full width of half-maximum (FWHM) of a Gaussian fit of a profile drawn perpendicular to the salivary ducts (at the end of the intraglandular ductal part) on a transversal plane of the data sets. A paired t-test was used to compare diameters before and after RT. Differences were considered statistically significant when \( p < 0.05 \).

Salivary-flow measurements were performed at the same time intervals and often on the same day, immediately after MR sialography. Stimulated parotid saliva was collected from both parotid glands simultaneously with Lashley cups, and mixed submandibular and sublingual saliva was collected from the floor of the mouth using a pipette. Stimulation was achieved by applying 50 \( \mu \)L of a 5% acid solution to the mobile part of the tongue every 1 min, and saliva collection was carried out for 10 min (25).

**RESULTS**

Magnetic-resonance sialography was performed successfully, and was well-accepted by all 9 patients. The repositioning of the RT immobilization mask at 6 weeks and 6 months post-RT was still good, and there was no need to make any new masks. The 3D image registration of the pre-RT MR sialograms with the post-RT MR sialograms and the CT data, and consequently the 3D dose distribution, was inspected visually, and it was considered satisfactory in all cases. The body contours were in good agreement, and no differences >2–3 voxels were observed when checking on specific points. The average diameter of the parotid ducts for this group of patients was 2.1 mm (standard deviation (SD), 0.5 mm) pre-RT, 2.2 mm (SD, 0.8 mm) at 6 weeks post-RT, and 2.3 mm (SD, 0.5 mm) at 6 months post-RT. For the submandibular ducts, the average diameters pre-RT, at 6 weeks post-RT, and 6 months post-RT, were 2.2 mm (SD, 0.5 mm), 2.0 mm (SD, 0.3 mm), and 2.1 mm (SD, 0.4 mm), respectively. The diameters as measured 6 weeks and 6 months post-RT were not statistically different from the diameters measured before RT (\( p > 0.05 \) in all cases).

**Visibility of the salivary ducts**

We assessed the visibility of the salivary ducts of 18 parotid glands and 16 submandibular glands. Two submandibular glands were excluded because they were in the vicinity of the operated area. One patient was lost from the 6-month post-RT follow-up. In general, the trajectory of the extraglandular parotid duct (Stensen’s duct) was visible on the transverse planes of the sialograms. The small parotid-duct branches were detectable as small, hyperintense dots in the hypointense surrounding of the parotid tissue on the transverse planes. Scrolling through the sagittal planes at the level of the parotid glands, the full trajectory of the small ducts as they converged from the second-order branches to the first-order branches, and eventually to the main intraglandular parotid duct, could be nicely followed (Figs. 3a, 4a, 5).

From the 300 salivary-duct parts (both parotid and submandibular) that were evaluated, there was discussion...
Consensus was reached after comparison of the pre- and post-RT MR sialograms. The visibility score of the parotid ducts was the maximum of 4 for all parotid glands, and was constant during the follow-up scans for those parotid glands that received a mean dose of $20 \text{ Gy}$. The visibility score was reduced for all other glands at 6 weeks post-RT, and started to improve for some patients at 6 months post-RT (Fig. 6). An interesting observation was that the intraglandular main parotid duct (part 1) was always visible, pre-RT, and post-RT. The average dose to that part was 33 Gy (SD, 13 Gy), similar to the average mean dose to the whole parotid gland, which was 35 Gy (SD, 13 Gy).

The changes in visibility score post-RT were due to the reduced visibility of the other ductal parts, the extraglandular and intraglandular small parotid ducts. The continuity of the smaller duct branches to the larger ones was lost. There was no indication of regional damage to the small ducts within the gland. The dose to parts 3 and 4 of the parotid duct was 25 Gy (SD, 17 Gy) and 33 Gy (SD, 22 Gy), respectively. The dose to part 3 was lower because it is situated superficially to the masseter muscle, and that part is mostly spared by IMRT, while part 4 is situated more medially and is closer to the high-dose area.

The full trajectory of the submandibular ducts was visible (maximum score, 2) for all submandibular glands pre-RT. The visibility score remained unchanged in one patient at post-RT measurements. In that patient, the mean dose to the left and right submandibular glands was 15 Gy and 2 Gy, respectively. For all other patients, only intraglandular part 1 was visible at 6 weeks post-RT. The visibility score did not improve at 6 months post-RT (Fig. 7), as it did for the parotid ducts. The average mean dose to the submandibular glands and ducts was higher than that to the parotid glands, at 62 Gy (SD, 8 Gy). They were included in the high-dose volume, because no treatment-planning effort was made to spare them.
The signal intensity of the whole salivary-gland tissue appeared to be higher post-RT compared to that pre-RT (Figs. 6, 7).

**Saliva measurements**

Salivary-flow measurements were successful in all 9 patients pre-RT and in 8 patients post-RT. One patient, who was excluded from the analysis, experienced pain on the floor of the mouth during stimulation with the citric acid at the post-RT follow-up, and the measurement had to be stopped. The MR sialography, however, was performed in that case.

The average amount of saliva collected from the parotid glands in 10 min was 1.7 mL (median, 1.2 mL) pre-RT, and 0.3 mL (median, 0 mL) and 0.3 mL (median, 0 mL) 6 weeks and 6 months post-RT, respectively. Despite the fact that the visibility score of some parotid ducts improved to maximum of 4, at 6 months post-RT, no saliva was collected from them.

Saliva from the submandibular glands could not be measured separately as from the parotid glands. The saliva collected from the floor of the mouth was assigned to both of the submandibular glands. The average amount of saliva pre-RT was 3.4 mL (median, 3.6 mL), and was reduced to 0.2 mL (median, 0 mL) and 0.1 mL (median, 0 mL) 6 weeks and 6 months post-RT, respectively.

**DISCUSSION**

In this prospective study, a 3D MR sialography protocol was applied, for the first time, to patients receiving RT for head-and-neck tumors. The MR sialography was performed using a heavily $T_2$-weighted sequence that allows imaging of the salivary ducts because the saliva appears hyperin-
tense, and the surrounding tissue appears hypointense (10). The use of the same RT immobilization mask, every time the patient was scanned, resulted in successful image registration of the MR sialograms pre-RT with those post-RT, and of the MR sialograms with the planning CT and consequently with the dose distribution.

The comparison of MR sialographic images of patients pre-RT and post-RT revealed radiation-induced changes in the visibility of the salivary ducts. The visibility of the whole trajectory of the salivary ducts as described by a visibility scoring system was reduced post-RT in comparison to that pre-RT. In healthy volunteers, however, the visibility score was reproducible in long-term time intervals. Thus it can be concluded that the reduced visibility score in patients indicated a lack of saliva (hyposalivation).

Mainly, the extraglandular parts of both the parotid and submandibular ducts were not visible post-RT, while the intraglandular main duct was always visible, pre- and post-RT (Figs. 3–5, 7). The diameters of ducts, as measured at the end of the intraglandular main duct (part 1), were similar to those observed in healthy volunteers (16).

Furthermore, the diameters of ducts post-RT were not significantly different from those pre-RT, for this group of patients. This finding suggests that there was no dilatation of the ducts due to obstruction that could possibly explain the lack of saliva in the extraglandular parts post-RT (9, 12). This is in accordance with what was observed by Kashima et al. (26). In that study, a less detailed pattern of the parotid duct, without small-duct filling, was observed using X-ray sialography 20 weeks post-RT. Similar observations were made with MR sialography. The small-duct branches could not be visualized for some of the parotid glands post-RT (Fig. 4). Whether that was because of the higher signal intensity of the parotid tissue itself post-RT, or because the small ducts were damaged (22), cannot be concluded. It seemed that the signal intensity was homogeneously increased in the whole salivary-gland tissue, even if the dose was not homogeneously distributed.

Fig. 5. An oblique transverse plane of the three-dimensional magnetic resonance (3D MR) sialogram (TR/TE 6,000 ms/190 ms) of a patient, at a level through the base of maxilla that includes a segment of parts 3 and 4 of the parotid ducts before radiotherapy (RT), 6 weeks post-RT, and 6 months post-RT. The hyperintense circular area is a part of the tube containing the MnCl₂ · 4H₂O solution that was used for signal normalization. The areas within the white frames at left are expanded at right. Arrows indicate the position of part 4 of the parotid ducts. At 6 weeks post-RT, that part was not visible in this patient.
The signal intensity of the salivary glands and, in general, of the rest of the tissues appeared to be higher post-RT (Figs. 5, 7). This was likely due to edema. Edema is a known radiation-induced tissue reaction, and edematous tissue appears hyperintense on T2-weighted MR imaging (27). Furthermore, it is possible to follow how, when, and for which tissues these effects decrease in time, by repetitive imaging. This increases the value of the information, and gives a four-dimensional character to MR sialography. The next step would be to investigate the possibility of quantifying this information and, if possible, establish a correlation between tissue changes and spatial dose distribution. The quantitative comparison between pre-RT MR images and those post-RT is not straightforward. The difficulty lies in the fact that the intensity of the signal in an MR image is sensitive to the system receiver and image-reconstruction settings. Therefore, a relative comparison with the help of a water solution or a tissue-like object, with a constant in time T1 and T2 properties, could be an option. This option should first be validated in healthy volunteers.

The visibility score of the salivary ducts was produced by a subjective method, but it nevertheless reflects the radiation-induced changes to the salivary system and quantifies qualitative information. In addition, it indirectly provides some functional information. In brief, the first step of saliva production takes place in the acinar cells, and the second step takes place in the ductal cells. From there, saliva is transferred to the excretory ducts, and then drains into the oral cavity. Therefore, damage to one or both of the above saliva-production steps is reflected in the reduction of the salivary-duct visibility score.

Far more data will be needed to support any correlation between dose and visibility score. However, the trend that we observed in our data was for a relatively low mean dose to the salivary glands, which in this group of patients was about 20 Gy, no changes in visibility score were observed post-RT. Above 20 Gy, however, a lower score than the pre-RT score was recorded, which means that the salivary-duct trajectory was partially visible. The increased score at 6 months post-RT compared to that at 6 weeks post-RT for the parotid ducts of some patients suggests that a repair mechanism may have started. However, the same cannot be concluded for the submandibular glands and ducts. The dose received by the submandibular glands was, on average, two times higher than that of the parotid glands.

We must point out that the MR sialography in this study was performed without the use of any contrast medium or stimulation. Consequently, it imaged the salivary-duct system at rest. About 70% of the salivary production at rest comes from the submandibular, sublingual, and minor salivary glands spread out in the oral cavity. During gustatory stimulation, while drinking and eating, about 60% of the saliva is produced by the parotid glands (9). Lack of unstimulated salivary flow, however, might play an important role in the subjective feeling of xerostomia that patients experience after radiotherapy. Hence, future studies should investigate whether qualitative and quantitative findings from MR sialographic imaging correlate with the perception of a patient’s dry mouth, as derived from patient-completed quality-of-life assessments. Patient self-reported scores should be the main endpoint when evaluating xerostomia (28).

Nevertheless, the standard method of quantifying xerostomia is with salivary-flow measurements using Lashley cups (25), which is why we used this method in our study as well.

Saliva was collected post-RT from those parotid glands that received a mean dose <20 Gy, and the full salivary-duct trajectory was still visible in the MR sialograms. There were parotid glands, however, from which no saliva was collected at 6 months post-RT, despite the fact that the whole duct trajectory could be visualized again. This might be because the saliva composition was not normal and could not flow as it did pre-RT, or because the lag phase of those glands at that stage was longer than the 10-min measure-

Fig. 6. Duct visibility score vs. parotid mean dose at 6 weeks post-RT (a) and 6 months post-radiotherapy (RT) (b).
ment time. It should also be taken into account that there is a variation in the salivary measurement itself of about 27% (1 SD) in healthy volunteers (29).

Based on salivary-flow measurement and the visibility of submandibular ducts, the salivary function of the submandibular glands decreased even more at 6 months post-RT. The amount of saliva collected from the floor of the mouth was very little, and that could explain why the full trajectory of the submandibular ducts was no longer visible. There is also a certain detection and resolution limit in all imaging modalities. We should be aware of this when evaluating data and when the salivary ducts are not visible.

However, to establish a correlation between salivary-flow measurements (10 min of measurement time) and 3D MR sialography (8–10 min of scan time), more patient data are required, and most importantly, the acquisition of MR sialographic images should replicate the salivary-flow measurements. Preliminary results from a pilot study performed on healthy volunteers at our institute showed that it was possible to acquire sialographic images during and after salivary stimulation with 50 μL of a 5% acid solution to the mobile part of the tongue every 1 min. The signal intensity of the parotid glands and duct volumes increased by approximately 40% during stimulation, relative to the unstimulated scan. After stimulation, the signal intensity in the parotid ducts returned to baseline, but this was not the case for the parotid glands (30). The application of such a protocol to patients should be further investigated. Morimoto et al. (31) presented qualitatively similar results to those of Astreinidou et al. (30). They acquired 2D MR sialography images of a single parotid gland and duct, before and after single-shot stimulation with citric acid. They observed a time-dependant signal-intensity change of the main parotid duct that seemed to correlate with the total saliva volume, measured with the spitting method. With this method, however, the flow from each parotid gland is not measured separately, as with the Lashley cups method. That would be necessary when investigating parotid-gland function after RT. Nevertheless, it is clear from the study of Morimoto’s, that MR sialography allows functional evaluation of the

Fig. 7. An oblique transverse plane of the three-dimensional magnetic resonance (3D MR) sialogram (TR/TE 6,000 ms/190 ms) of a patient, at a level through the transverse process of the atlas (C1) and the mandible that includes a part of the submandibular ducts, before radiotherapy (RT), 6 weeks post-RT, and 6 months post-RT. The areas within the white frames at left are expanded at right. Arrows indicate submandibular ducts. Submandibular ducts were not visible post-RT. S = submandibular glands; P = parotid glands.
salivary glands, and merits further investigation. Particularly, 3D MR sialography, in combination with salivary stimulation, has the potential to provide spatial information about the salivary-gland function of both the parotid and submandibular glands bilaterally and simultaneously.

In recent years, diffusion-weighted MR imaging (DW-MRI) has also been employed to investigate salivary-gland function (32–34). Diffusion-weighted MRI produces image contrast due to the random movement of water in tissues. The apparent diffusion coefficient (ADC) is a parameter that quantifies DW-MRI. The interpretation of ADC values, however, should be performed with care, because they are influenced not only by motion due to diffusion, but also due to perfusion and salivary flow (35). Irrespective of the sensitivity of ADC values to the acquisition and analysis of DW-MRI images, the experience from preliminary studies (33–35) is that DW-MRI evaluates to a certain degree the water mobility in the salivary glands. That, in combination with MR sialography, which is a straightforward method to image the saliva in the salivary ducts, could provide insights into the mechanism of saliva production and transfer from the acinar cells to the salivary ducts.

**CONCLUSIONS**

Magnetic-resonance sialography is a noninvasive 3D imaging technique wherein saliva itself is imaged along the full trajectory of the major salivary ducts, from the intraglandular space to the oral cavity. We demonstrated that MR sialography can depict radiation-induced changes to the salivary glands and ducts post-RT. Registration of those radiation-induced effects to the 3D dose distribution is possible, and with repetitive imaging, they can be followed over time post-RT. This combination makes MR sialography a novel and promising tool for investigating radiation-induced xerostomia.

**REFERENCES**


