Absorbed Doses and Energy Imparted From Radiographic Examination of Velopharyngeal Function During Speech

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Absorbed doses of radiation were measured by thermoluminescent dosimeters (TLDs) using a skull phantom during simulated cinefluorographic and videofluorographic examination of velopharyngeal function in frontal and lateral projections. Dosages to the thyroid gland, the parotid gland, the pituitary gland, and ocular lens were measured. Radiation dosage was found to be approximately 10 times less for videofluoroscopy when compared with that of cinefluoroscopy. In addition, precautionary measures were found to reduce further the exposure of radiation-sensitive tissues. Head fixation and shielding resulted in dose reduction for both video- and cinefluoroscopy. Pulsing exposure for cinefluoroscopy also reduced the dosage.

KEY WORDS: absorbed doses, energy imparted, cineradiography, videofluoroscopy, velopharyngeal closure

Radiographic assessment has become essential in examining the function of the soft palate and the pharyngeal walls in patients with velopharyngeal insufficiency (VPI) (Skolnick, 1970; Williams and Bzoch, 1972; Shprintzen et al, 1974; Williams et al, 1976). In 1977 Skolnick published a call for the interdisciplinary approach to the radiologic study of velopharyngeal function. The examination, as suggested by Skolnick, should be a cooperative and joint endeavor between the radiologist and other clinicians. Also of importance is the use of effective means to reduce radiation exposure for patients and for all involved personnel.

Patients undergoing radiography for velopharyngeal insufficiency are typically young children. Organs such as the thyroid gland (Clark, 1955; Hempelmann et al, 1967; Hempelmann, 1968; Doida et al, 1971; DeGroot and Paloyan, 1973; Modan et al, 1974; Hempelmann et al, 1975; Silverman and Hoffman, 1975; UNSCEAR, 1977; BEIR, 1980) and the salivary glands (Belsky et al, 1972; Modan et al, 1974) are in the vicinity of the radiation field. Furthermore, many of the patients are born with clefts of the palate, alveolus, or both, which require repeated radiographic examinations including intraoral radiography, cephalography, and panoramic surveys exposing the head and neck region to radiation. It is therefore important to perform radiographic examinations with the absorbed doses kept as low as possible (ICRP, 1977) in order not to add unnecessary radiation hazard to these children.

Hempelmann (1968) reported the incidence of thyroid carcinoma and nodularity against the total cumulative thyroid dose in different irradiated and nonirradiated populations. He found what could be a linear dose response without a threshold over 200 mGy for nodularity. In his studies, the risk of developing carcinoma ranged from 0 to 5.5 cases per 10^6 individuals exposed, and that of nodularity ranged from 38 to 53 cases per 10^6 individuals exposed to a 10-mGy thyroid dose per year. Modan et al (1974) reported an increase of malignant tumors in the thyroid gland of one per 1,000, which was statistically significant, and a 0.4 per 1,000 increase in the parotid glands after irradiation with absorbed doses of a magnitude as low as 65 mGy. In the patient with a cleft or with VPI, it is possible to exceed this value by a combination of a number of different radiographic examinations if the technical factors are not under strict control. A large radiation field including adjacent organs multiplies the radiation absorbed dose as well as the total radiation load (the energy imparted). For example, the absence of shielding increases the thyroid dose. Low sensitivity film-screen systems require more exposure, and nonpulsing, continuously exposing cineradiographic systems result in an increased absorbed dose. Improper balancing of other exposure factors, especially the tube voltage, also increases the absorbed dose.

In comparison, the thyroid dose from one single lateral exposure of the head has been gradually reduced from approximately 5 mGy in 1953 to approximately 0.005 mGy in 1985 by balancing all radiographic factors in the system (Franklin, 1953, 1973; Cohen, 1958; Hollender and Lysell, 1964; Block et al, 1977; Bankvall and Hakansson, 1982; Eliasson et al, 1984, 1985). One mGy equals 100 mrad.
Thus the absorbed dose in a certain organ can vary with a factor of 1,000 depending on the radiographic technique used.

The purpose of the present study was to measure the radiation absorbed doses in different organs in the head and neck region and to compute the mean energy imparted from velopharyngeal cinefluorography and videofluorography. Furthermore the dose-reducing effects of different radiographic factors were evaluated in order to recommend techniques with a favorable benefit-dose ratio.

**Material and Methods**

**Radiographic Procedures**

Radiation absorbed doses were registered in a phantom head using radiographic procedures equivalent to cinefluorographic and videofluorographic examinations of velopharyngeal function in patients during speech (Table 1). The examination was performed in lateral and frontal projections using a head fixation device (cephalostat) that permits a strict collimation of the radiation field. Consequently, the thyroid gland was exposed to only scattered radiation. Each sequence comprised an average of 5 seconds during adjustment of the strictly collimated radiation field, 3 seconds for setting of the automatic exposure control, and 40 seconds of radiographic uptake. The exposures were performed with and without thyroid shielding, which consisted of a soft leaded collar. The technical parameters used were the same as in a typical patient examination.

The radiographic equipment consisted of a six-pulse generator (Siemens Tridoros Optimatic), an x-ray tube with rotating anode (Siemens Bi 150/30/50 R), an image intensifier (Siemens Sirecon II), an Arriflex cinecamera running 25 frames per second, and a Vidicon camera connected to a TV-monitor and a videorecorder (Fig. 1). The tube was equipped with a multiplanar collimator. The inherent filtration was stated by the manufacturer to correspond to 2 mm Al.

The half value layer was measured at a tube voltage of 75.5 kVp to be 2.7 mm Al. The total filtration was calculated using current graphs (Physics of Radiodiagnoses, Scientific Report Series 6, 1977) to correspond to 2.5 mm Al. The system had automatic exposure control. The automatic exposure control was set to give a mean optical density above fog of about 0.5. Radiographic exposure was triggered by the cinecamera and generated 25 times per second.

Prior to dosimetry the relation between x-ray exposure time and total running time during cine-uptake was determined by means of an oscilloscope with memory function (Tektronix 510 3N) that measured the x-ray output from the collimator opening with a radiation-sensitive diode. At 25 pulses per second, the exposure time—expressed as full pulse width at half maximum—ranged from 3.4 to 3.6 milliseconds using different absorber thicknesses with the automatic exposure control. Therefore the average x-ray exposure time was 8.8 percent of the running time (Fig. 2).

The actual tube voltage at the different kVp settings was measured by means of an electronic penetrantometer (Digi-X) and was found to lie less than 7 percent below the settings.

**Dosimetry**

Dosimetry was performed using a phantom head that consisted of a human skull embedded in tissue equivalent anatomically shaped material (Alderson RANDO). “Tissue equivalent” indicates that the soft matter has the same radiophysical properties as the soft tissues in a patient, with specific reference to density, atomic number, and thickness. The phantom was approximately the size of an adolescent head. Measurements of absorbed doses were carried out with the technique of thermoluminescence dosimetry. The dosimeters were lithium fluoride (LiF) ribbons (3.2 mm x 3.2 mm x 0.9 mm) manufactured by Harshaw Chemical Co. (TLD 100). Individual calibration constants were...
determined for each dosimeter to correct for the differences in sensitivity (Carlsson et al., 1968). Twenty-eight dosimeters were used and were handled according to a standardized procedure. Before irradiation the dosimeters were thermally treated at 400° C for 1 hour. After irradiation the dosimeters were chemically treated with methanol that contained 12 mol HCl per cubic meter and then heated to 80° C for 30 minutes. The TLDs were placed in 11 locations, which represented the organs listed in Tables 2 and 3. A Toledo TLD Reader, Model 654 provided the readout value, which was corrected for the background as measured by three to five dosimeters. The absolute sensitivity measurement for all the dosimeters was determined for each series with five to seven randomly chosen dosimeters. These dosimeters were irradiated together with an ionization chamber on a lucite phantom. The ionization chamber was exposure calibrated at The Swedish National Standard Dosimetry Laboratory. The conversion factor was 9.2 mGy per roentgen, according to Wyckoff (1983).

To obtain sufficiently high absorbed doses in the dosimeters outside of the primary field of irradiation, three identical cine-sequences of 5 +3 +40 seconds were performed on each of five trials. Each measurement series was independently repeated on five different occasions. The entrance dose, thyroid dose, and parotid dose during videofluorography were tested on two occasions, once with and once without a thyroid shielding in both frontal and lateral projections. The energy imparted was calculated from the entrance doses according to Harrison (1983):

\[ \varepsilon = D_0 \cdot A_0 \int_0^d e^{-\mu x} \cdot \left( \frac{f + x}{f} \right)^2 dx \]

where \( \varepsilon \) is the energy imparted
\( D_0 \) is the surface dose
\( A_0 \) is the surface area
\( d \) is the thickness of the absorber
\( e \) is the base of the natural logarithm system
\( \mu \) is the linear attenuation coefficient
\( x \) is the depth in the patient and
\( f \) is the focal spot-skin distance.

**RESULTS**

In frontal projection a 40-second cinefluorographic sequence plus 5 +3 seconds adjusting time gave an entrance dose to the skin of the lips of 30 mGy. The doses ranged from 0.1 mGy in the thyroid region to 10 mGy on the tongue (see Table 2).

In lateral view, the cinefluorographic sequence gave an entrance dose to the skin of 6 mGy. The organ doses ranged from 0.08 mGy (thyroid gland) to 3.5 mGy (parotid region on the entrance side). Significant differences between entrance and exit side were found in the regions of the parotid and the submandibular glands. For all other regions the mean values of the left and right sides are shown in Table 3. The precision of the measurements (expressed variation coefficient in percentage) of the five determinations ranged from 11 percent to 74 percent, with the highest values for dosimeters situated near the border of the primary field. The average precision (expressed as the square root of mean variance) was 37 percent for the frontal and 35 percent for the lateral determinations. Excluding the cervical vertebral body and the submandibular glands, which are nearest to the border of the field, gives an average precision of 27 percent for regions well within and outside the primary field. The energy imparted was calculated to 5.2 mJ for a frontal and 1.4 mJ for a lateral cine-sequence, totaling 6.6 mJ. Videofluorography resulted in approximately one-tenth of the dose achieved with cinefluorography. Using the thyroid collar reduced the thyroid dose by 60 percent in the frontal and 20 percent in the lateral projection.

**DISCUSSION**

The present study shows that the doses of absorbed radiation in important organs obtained from velopharyngeal cinefluorography can be kept low (for example, below 0.2 mGy for the thyroid region). The entrance doses were, however, ten times higher than those in conventional radiography of the facial skeleton with high-sensitive screen-film systems (Julin and Kraepelien, 1984). The total radiation load, i.e., the energy imparted, was nevertheless of the same magnitude as that from a full series of four conven-

<table>
<thead>
<tr>
<th>Number of TLDs</th>
<th>Location</th>
<th>Dose (mGy)</th>
<th>SD† (mGy)</th>
<th>SD/Mean‡ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Thyroid gland</td>
<td>0.10</td>
<td>0.018</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>Parotid gland</td>
<td>0.29</td>
<td>0.047</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Submandibular gland</td>
<td>1.6</td>
<td>0.90</td>
<td>56</td>
</tr>
<tr>
<td>1</td>
<td>Dorsum of the tongue</td>
<td>9.6</td>
<td>1.80</td>
<td>19</td>
</tr>
<tr>
<td>1</td>
<td>Palatal mucous membrane</td>
<td>5.8</td>
<td>0.80</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>Pituitary gland</td>
<td>0.51</td>
<td>0.14</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>Eye lens</td>
<td>0.38</td>
<td>0.042</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>Cervical vertebra, body</td>
<td>0.61</td>
<td>0.45</td>
<td>74</td>
</tr>
<tr>
<td>1</td>
<td>Atlas, anterior border in occlusal plane</td>
<td>9.0</td>
<td>4.50</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>Entrance, lips</td>
<td>29.8</td>
<td>4.70</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Exit, back of the neck</td>
<td>0.28</td>
<td>0.10</td>
<td>36</td>
</tr>
</tbody>
</table>

* From a complete frontal 40 + 8 seconds velopharyngeal cinefluorographic sequence.
† SD is the standard deviation of five independently repeated determinations.
‡ Square root of mean variance, 36.5.
### TABLE 3 Mean Radiation Absorbed Doses—Lateral*

<table>
<thead>
<tr>
<th>Location of TLDs</th>
<th>Dose (mGy)</th>
<th>SD† (mGy)</th>
<th>SD/ Mean‡ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid gland</td>
<td>0.078</td>
<td>0.015</td>
<td>19</td>
</tr>
<tr>
<td>Parotid gland right</td>
<td>0.55</td>
<td>0.11</td>
<td>20</td>
</tr>
<tr>
<td>Parotid gland left</td>
<td>3.5</td>
<td>1.20</td>
<td>34</td>
</tr>
<tr>
<td>Submandibular gland right</td>
<td>0.33</td>
<td>0.15</td>
<td>45</td>
</tr>
<tr>
<td>Submandibular gland left</td>
<td>1.9</td>
<td>0.62</td>
<td>34</td>
</tr>
<tr>
<td>Dorsum of the tongue</td>
<td>1.10</td>
<td>0.31</td>
<td>28</td>
</tr>
<tr>
<td>Palatal mucous membrane</td>
<td>0.77</td>
<td>0.16</td>
<td>21</td>
</tr>
<tr>
<td>Pituitary gland</td>
<td>0.105</td>
<td>0.027</td>
<td>26</td>
</tr>
<tr>
<td>Eye lens</td>
<td>0.089</td>
<td>0.025</td>
<td>28</td>
</tr>
<tr>
<td>Cervical vertebra, body</td>
<td>0.16</td>
<td>0.07</td>
<td>44</td>
</tr>
<tr>
<td>Atlas anterior surface occlusal plane</td>
<td>1.14</td>
<td>0.46</td>
<td>40</td>
</tr>
<tr>
<td>Entrance skin</td>
<td>5.8</td>
<td>1.40</td>
<td>24</td>
</tr>
<tr>
<td>Exit</td>
<td>0.29</td>
<td>0.11</td>
<td>38</td>
</tr>
</tbody>
</table>

* From a complete lateral 40 + 8 seconds velopharyngeal cinefluorographic sequence. The beam was entering from the left side.
† SD is the standard deviation of five independently repeated measurements.
‡ Square root of mean variance, 34.5.

Conclusions

The doses to radiation-sensitive organs in the head and the energy imparted can be kept low in radiographic examination of the velopharynx, provided that all radiographic factors are properly balanced. Findings from the present study have led us to make the following recommendations for velopharyngeal cinefluorographic and videofluorographic examinations to enhance favorable benefit-dose ratios:

1. Use of a head fixation device (cephalostat) to allow strict collimation of the irradiated field
2. Limited exposure time
3. The choice of videofluorography over cinefluorography
4. Avoidance of nonsynchronized pulsing exposure system for cinefluorography
5. Examinations should be planned, guided, and interpreted as a cooperative and joint endeavor between the radiologist and the other clinicians.

### REFERENCES

Commentary

The public is constantly being reminded, through newspaper and magazine articles along with radio and television talk shows, of the danger of x-rays. It is important, therefore, that those of us who are involved in the radiographic evaluation of the velopharyngeal sphincter be concerned about the doses of radiation received by our patients during the course of the examination. In the preceding paper Dr. Isberg and her colleagues provide us with the data.

Some of the terminology in the paper, particularly the dosimetry and the units of radiation and absorbed energy, may be confusing to the average reader who does not have a background in physics. However, the authors put the matter in perspective by comparing the dose rates from two-dimensional cinefluorography with that of a full series of facial x-rays, with the absorbed energy being comparable to "at most a few months of natural background radiation." By using videofluorography we can reduce this by one order of magnitude (a factor of ten). Personally, I would not hesitate to use additional views (base, Towne, or obliques) when indicated. Diagnostic radiographic procedures are performed because we believe that the benefits of the procedure outweigh the risks. But we must do everything we can to keep the radiation exposure to the patients and ourselves as low as possible.

Careful adherence to the principles of radiation safety (i.e., shielding, limited exposure time, and limiting the size of the field being radiated) is essential. The importance of close cooperation between the radiologists and the other clinicians involved in assessments of velopharyngeal valveing can not be overemphasized. Isberg et al have convincingly pointed out the low risk of videofluorographic procedures while still pointing out how radiologists can reduce even further the small risk that remains.

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