Intraoperative and dynamic 3D rotational X-ray imaging
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Chapter 3

Cochlear implant electrode array insertion monitoring with intraoperative 3D rotational X-ray

Cochlear implantation with peroperative 3D-RX

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3.1 Introduction

Multielectrode arrays of cochlear implants are designed to stimulate the auditory nerve electrically to allow hearing in the sensorineural deaf. Crucial in cochlear implantation (CI) surgery is the correct insertion of the multielectrode array into the cochlea. The placement of the multielectrode array close to the modiolus is essential for optimal speech perception after implantation.[1] Normally, the surgeon performs a cochleostomy through which the multielectrode array of the CI is inserted into the cochlea. However, the procedure at times is difficult because of anatomical variations of the ear. Incomplete and wrong insertion of the multielectrode array has been recognized as a major complication.[2]

However, from the series of Hoffman et al. we know that only 1.2% of all performed implantations are wrongly inserted.[2] From the literature, we know that in cochlear implantation revision surgery, 17% up to 33% is due to positioning failure of the multielectrode array.[2-5] Further, of all wrongly inserted multielectrode arrays 94% needs re-intervention.[6] In addition, the indication for cochlear implantation has also broadened considerably in the last decade with congenital malformed ears, extensive cochlear otosclerosis and revision surgery becoming more frequent. Consequently, the surgical challenge has increased.[2] Proops et al. showed that especially cases with meningitis and otosclerosis can cause difficulties inserting the multielectrode array in respectively 39% and 38% of their patients.[7]

Some of the potential multielectrode array placement failures can be corrected per-operatively as long as the surgeon is aware of misplacing the multielectrode. Until now, incorrect multielectrode array positioning is most often revealed during the post-operative phase when revalidation fails and a following routine CT-scan reveals the cause. Neurophysiological measurements during the operation are helpful but not conclusive indicators for the multielectrode array position.

We are convinced that there is a need for perioperative imaging of the multielectrode array in the operating room. Until now, perioperative visual control of the multielectrode position is done with a conventional mobile C-arm image obtained in the modified Stenver’s view.[8] However, the C-arm based fluoroscopic images have low definition and are 2D whereas 3D would be preferred.

We describe the intraoperative application of the BV Pulsera with 3D-RX for checking per-operatively the multielectrode array position in the cochlea. The advantage of our technique is the high definition 3D images, which eliminate uncertainty of positioning the multielectrode array.
Fig. 1. Schematic drawing of the scan acquisition. The rotational C-arm rotates 200 degrees around the cochlea of interest making 375 low dose images. These images are reconstructed into a 3D set consisting of a 9-cm sphere using the mobile workstation.

### 3.2 Scanning technique

The prototype 3D-RX system is a mobile digital X-ray C-arm (Philips BV Pulsera, Best, the Netherlands), modified for motorized movement. A series of projection images is taken during rotation of the C-arm in 30 s. These scans are reconstructed with a Philips 3D-RA workstation into a 3D dataset.[9] The dose of each image in this scanning run is dynamically adjusted to obtain low-dose and best image quality. For inner ear imaging we used 450 images acquired over 200° with the highest magnification (Fig. 1). The reconstructed data set is a sphere with a diameter of 9 cm and 0.363 mm3 voxels. The patient’s head was placed on a radiolucent rest such as a carbon fibre surgery table to allow rotational imaging. For all scans, the system was aligned with external lasers pointing at the isocenter of the rotation (Fig. 2).
3.3 Procedure

The cochlear implantation was performed by two senior ENT surgeons of the university hospital Amsterdam as part of the Cochlear Implantation Amsterdam group. Once adequate exposure of the stapes, round window and basal cochlear turn is achieved the cochleostomy is performed. The multielectrode array (Nucleus 24 contour, Cochlear) was partially inserted into the cochlea. For the complex insertions correct position of the array was checked with a 3D-RX scan (Fig. 3 left panel). Next, the stylet was removed from the cochlear implant and full insertion into the cochlea was achieved. A 3D-RX scan was made to check optimal positioning in the cochlea (Fig. 3 middle and right panel). The procedure was finalized by our audiologist with neurophysiological assessment.

3.4 Results

We have been using the 3D-RX scanning system since February 2005 in every cochlear implantation. Twenty-three patients have been scanned according to the procedure described above (Table 1). Included in this series is one patient with otosclerosis (patient 9). In Fig. 4, a pre-operative coronal slice shows the potentially difficult route to the cochlea. Next to this Fig. 4, a perioperative 3D-RX image of patient 9 is shown with the multielectrode array in the right position before removing the stylet. Especially in these cases, per-operative 3D-RX scanning adds certainty in performing an optimal implantation. The images show good bone and implant detail (Fig. 3), allowing the surgeon to assess the position of the implant in the cochlea with certainty. In patient 5, our 3D-RX system enabled us to correct the incorrect multielectrode array position, avoiding revision surgery at a later date (Fig. 3 middle panel). Fig. 5 shows the pre- and postoperative CT of patient 5 and reveals no anatomical abnormalities. From the literature we know that cochlear implantation in post-meningitis patients has an increased failure rate, most likely due to small intra-cochlear obstructions.[7] Once discovered, the multielectrode array was removed, the stylet was reinserted, and a second implantation was performed with the same device (Fig. 3). The post-operative NRT measurements showed no damage to the device.
The scanning and reconstruction added 15 min to the surgical procedure. The surgery time including 3D-RX scanning was 1:41 h on average. The scan of the cochlea and implant can be viewed in any plane such as coronal, sagittal and axial direction on the workstation in the operation room. The presence of artefacts because of metal is low due to optimal system properties.

The effective dose of one scan series is 0.07 mSv (CT-scan ear 0.6-3 mSv).[10;11] The low-dose is mostly because of the small region scanned and the low-kV (≈70 kV) used. Xu et al. use 80 mAs to make a modified Stenver's view X-ray and the 3D-RX system a total of 225 mAs.[8] We have been using the 3D-RX scanning system since February 2005 in every cochlear implantation. Sixty-five patients were scanned according to the procedure described above. Included in this series are several patients with otosclerosis. In Fig. 4, a preoperative coronal slice shows the potentially difficult route to the cochlea. Next to this Fig. 4, a perioperative 3D-RX image is shown with the multielectrode array at the correct position before removing the stylet. Especially in these cases, per-operative 3D-RX scanning adds certainty in performing an optimal implantation. The images show good bone and implant detail (Fig. 3), allowing the surgeon to assess the position of the implant in the cochlea with certainty. In patient 5, our 3D-RX system enabled us to correct the incorrect multielectrode array position, avoiding revision surgery at a later date (Fig. 3 middle panel). The post-operative neuro response telemetry measurements showed no damage to the device.

Fig. 3. Intraoperative 3D-RX scans of a cochlear implantation; the images are approximately coronal slices in 45 mm by 45 mm field of view. (Left) Coronal slice of the first 3D-RX dataset. The multielectrode array is inserted until the white marking of the array (stylet in place). (Middle) Coronal slice of the wrongly placed multielectrode array in the cochlea (second scan) although fully inserted the multielectrode array curved in the first winding. (Right) Coronal slice of the fully inserted and properly placed (and curved) multielectrode in the cochlea (third scan).
Fig. 4. Comparisons of 3D-RX with other modalities top-left approximate Stenver’s view X-ray of patient 20. On the right-hand side, an approximate slice in the direction of the Stenver’s view of the same patient. Lower left-hand side, Coronal CT slices of patient 9. Clearly is seen the otosclerosis and the potentially difficult route to the cochlea. All CT images are made with a Philips MX8000Quad (Philips Medical Systems, Cleveland, OH, USA), slice thickness 0.6 mm. In the lower right per-operative 3D scan of patient 9, slice thickness 0.36 mm. Clearly in this coronal slice is the otosclerosis and the correct insertion of the multielectrode array in the cochlea.

Fig. 5. Left panel, pre-operative CT scan of patient 5. Shown are four coronal slices of the diseased ear. The images show no abnormalities. Right panel, post-operative CT scan of patient 5. Shown are four coronal slices of the diseased ear with cochlear implant. These images can be compared Fig. 3 right plane and show a similar position of the multielectrode.
3.5 Discussion

The 3D-RX system provides accurate intraoperative images with high detail during cochlear implantation. This technique helps the surgeon to obtain an optimal multielectrode placement and avoids failures. Insertion failures occasionally occur, but in otosclerosis, congenital malformed cochlea’s and post-meningitis patients the failure rate is considerably higher and this group would benefit mostly from intraoperative 3D-RX imaging.[2; 5; 7; 12] The use of intraoperative Stenver’s view radiography is helpful but does not show adjacent anatomic structures (Fig. 4). This would yield false negative images such as extra-cochlear unfolding and in the case of anatomical anomaly possibly false positives. The scanning adds 15 min to the surgery time and is justified with the gained precision. Also the standardisation of each implant position will become more important to obtain optimal end-hearing results; here the 3D-RX system will be of great help. We believe this system can potentially lessen revision surgery since the correct position of the multielectrode is verified during surgery. The radiation dose is less then a tenth of a regular CT-scan of the ear and five times a modified Stenver's view X-ray.

3.6 Conclusion

The intraoperative 3D-RX scanning technique makes high-quality images of the cochlea and the cochlear implant. It has added value since it gives certainty about the position of the multielectrode array in the cochlea. This technique has become routine during cochlear implantation in our institution.

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References


