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Radiation Risk Due to Shunted Hydrocephalus and the Role of MR Imaging–Safe Programmable Valves

Diagnostic radiology is a double-edged sword: While providing critical information that forms the basis of treatment, it adds to the risk associated with cumulative radiation given to the patient. Shunted hydrocephalus exemplifies this conundrum. Hydrocephalus is a common neurosurgical condition that affects individuals of all ages, and the most common method for managing hydrocephalus is the surgical implantation of a shunt system to divert the flow of CSF from the ventricles.[1,2] More than 125,000 shunts are implanted every year in the United States at a cost of US $2 billion.[3] Nearly half of this cost is associated with shunt revisions.[4]

Although most cases of hydrocephalus have clinical improvement with the insertion of a shunt, it is rare for the device to last a lifetime without complications.[2] Shunts can be obstructed and infected, and tubing may get disrupted, resulting in recurrence of symptoms. In 1 study, the shunt failure rate in children was reported to be 31% within the first year and 4.5% per year thereafter; the failure rate in adults was found to be comparable with that in children.[5] In another study, the overall shunt survival in pediatric patients was 62% at 1 year, 52% at 2 years, 46% at 3 years, and 41% at 4 years.[6] In a third study, the probability of shunt malfunction after 12 years was 81%.[7] The high incidence of device problems and the potential for serious consequences as a result, combined with patients who have cognitive problems expressing their symptoms, predicts frequent visits to emergency departments and urgent care centers.

The integrity of the tubing is checked by a series of x-rays of the head, chest, and abdomen; the size of the ventricles is assessed by CT of the head.[8] CT is often the preferred technique because of its wide accessibility, ease of use, and brief imaging period. Initial scans focus on finding abnormal pathologies, while subsequent scans are oriented toward assessment of the shunt, determination of stability of ventricular volume, and identification of related complications. This need for confirming the suspicion of a shunt malfunction by diagnostic radiology increases the risk for long-term effects of ionizing radiation.[9,10] The effective doses for x-rays are 0.1 (skull), 0.1 (chest), and 0.7 (abdomen) mSv, respectively; and for CT of the head, it is 2.0 mSv.[11] In other words, a visit to the emergency department will result in nearly the same amount of radiation that any healthy individual gets from background radiation (estimated at 3 mSv) during a year.[11] Despite this diligence in managing shunt problems, 2 of 3 patients who are investigated are not found to have shunt malfunction.[12]

Excessive exposure to radiation is of greater concern in children because rapidly dividing cells in children are more radiosensitive than those in adults.[13,14] Additionally, a longer lifetime for children allows the manifestation of radiation injuries, which have a long latency period before they become apparent in patients.[13] The National Council on Radiation Protection and Measurements estimated that during the past 2 decades the total exposure of the US population to ionizing radiation has nearly doubled.[15] Studies have shown that patients most prone to harm from diagnostic radiation are children and young adults[16]; individuals with medical conditions sensitive to radiation, such as diabetes mellitus and hyperthyroidism[17] (which are possible risk factors associated with normal pressure hydrocephalus)[18]; and individuals receiving multiple doses with time.[19] From the 72 million CT scans performed in the United States during 2007, 1 study estimated that 29,000 future cancers and 14,500 deaths could result from radiation (assuming the cancer incidence to be 0.04%).[20,21] The radiation doses that an organ receives from a typical CT study involving 2–3 scans are in the range of direct statistical significance for increased cancer risk.[14] There are significant associations between the estimated radiation doses provided by CT scans to red bone marrow and brain and subsequent incidence of leukemia and brain tumors. Assuming typical doses for scans done after 2001 in children aged younger than 15 years, cumulative ionizing radiation doses from 2–3 head CTs could almost triple the risk of brain tumors and 5–10 head CTs could triple the risk of leukemia.[22] In 2002, the International Commission on Radiologic Protection stated, "The absorbed dose to tissue from CT can often approach or exceed the levels known to increase the probability of cancer."[23] Although some studies may rely on unproven scientific assumptions or have not finished collecting data, they illustrate an important consideration for maintaining diagnostic radiation exposure at a minimum.

The use of MR images can reduce the amount of ionizing radiation exposure to patients with shunts, as opposed to the use of x-rays and CT scans. Reducing radiation delivered to patients could lessen the incidences of long-term effects of radiation, most notably cancer, because the risk of all solid cancers increases linearly with increasing radiation doses up to 2.5 Sv.[14] Fast TSE T2 sequences are commonly used in rapid brain MR imaging.[24-28] Despite their utility, at least 2 limitations have been described. One is the lack of sensitivity in identification of extra-axial and parenchymal blood products that can result from overdrainage.[29,30] The other is decreased catheter delineation compared with CT.[28] Rapid steady state gradient recalled echo scanning has been advocated to eliminate the problems associated with rapid brain MR imaging by using fast TSE T2 sequences.[31]

A common concern with shunt function is the over- or underdrainage resulting from the mismatch of opening pressure of the valve to the needs of the patient.[7] To address this issue of mismatch without the need for reoperation, programmable valves that allow clinicians to change the setting of the opening pressure were designed. These programmable valves are noninvasively ad-

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justed through the application of a magnetic mechanism by using an external programmer. The first-generation designs involved confirmation of the setting of the valve by x-rays, leading to more radiation to the patient. However, when a patient is in close proximity to an external magnetic field, there is a possibility of an unintentional pressure setting alteration.[32] As a result, individuals with such programmable valves need adjustment after they undergo MR imaging.

In addition, external magnetic fields found in devices such as video game systems, children's toys, cell phones, kitchen appliances, loud speakers, iPads (Apple, Cupertino, California), and so forth have been shown to cause valve malfunctions in shunts.[33-38] This exposure not only contributes to the inability of the shunt device to work properly but leads to increased hospital visits and thus increased diagnostic scans from CT and x-rays. There have been specific instances of these cases: A boy playing with toy magnets altered the valve settings on his shunt,[38] a man with a programmable shunt attempted suicide by using an electromagnet,[39] an iPad 2 altered the setting on the valve of a 4-month-old girl,[37] and the shunt setting of a 5-year-old boy was changed by a household electric appliance.[40]

Of the programmable valves used in shunts today, only a few are MR imaging–safe. The effect of external magnetic fields of 3T MR imaging scanners on 5 programmable shunts that are available for use in hydrocephalus was investigated. Of these, only Miethke ProGav (B Braun, Melsungen, Germany) and Polaris (Sophysa, Orsay, France) valves were not altered in the presence of an external magnetic field up to 3T. On the other hand, the Sophy (Sophysa) valve was altered between 18 and 27 mT; the Strata (Medtronic, Goleta, California) valve, between 22 and 36 mT; and the Codman Hakim (Codman & Shurtleff, Raynham, Massachusetts; regular and integrated with Siphon Guard; Codman & Shurtleff) valve, between 43 and 54 mT. The key feature that prevents inadvertent change in the setting of the valve is a locking mechanism that needs to be overcome when the setting is changed deliberately.[36]

These MR imaging safe–programmable valves avoid the need for radiation exposure after diagnostic MR imaging. Additionally, the problems resulting from external magnetic fields from commercial sources can be reduced, if not eliminated. The ability to observe CSF flow through shunt tubing is another advantage of using MR imaging for detection of proper functioning of the device.[41,42] The pulsatile movement or flow of the CSF in the cerebral aqueduct has been illustrated by several groups by using the cerebral aqueductal flow void found on MR images. This technique sensitizes MR images to velocity changes in a specific direction and is helpful in quantifying CSF production when monitoring patients with hydrocephalus.[43,44] Phase-contrast MR imaging can display the pathologic CSF flow dynamics noninvasively and allow assessment of the progression of the disorder.[44]

Although MR imaging–safe shunts are an improvement for the management of hydrocephalus, shunts are intricate devices and come with a list of complications. The integrity of the shunt still needs to be checked by using x-rays. MR imaging scanners are not available ubiquitously. Therefore, steps should be taken not only to minimize the risk for long-term complications of ionizing radiation but for designing alternative shunt-free treatment strategies that go beyond managing hydrocephalus and cure the disorder. Such alternatives to surgical treatment not only avoid the trauma of surgery but also eliminate the life-long exposure to excess radiation from an implanted shunt, especially in a neonate.

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