The Safe Radiotherapy in Patients with Implanted Cardiac Pacemaker

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Abstract

Radiotherapy to cancer patients having implanted cardiac pacemakers (ICPs) is challenging decision. The literature reported serious life threatening complications secondary to ICP malfunction. As the number of patients with ICPs requiring radiation therapy is on rise, it is recommended that cardiologist, physicist and radiation oncologist be aware of the potential risks to ICPs and their prevention. Most of radiotherapy centers do not have internal policy and procedures (IPPs) to handle cancer patients with ICP receiving radiation. This article reported three radiotherapy courses in two cancer patients with ICP treated at our center. The Pub med and Cochrane database were searched for the potential hazards and effects of radiotherapy on patients having ICPs. The reviewed literature showed that modern multi-programmable pacemakers are very sensitive to radiation therapy in comparison to old generation pacemakers. The radiation therapy can destroy ICP or at least can affect its function. There is no safe radiation threshold for ionizing radiation, however it is not contraindicated. Megavoltage radiation can be safely delivered to patients with cardiac pacemakers provided direct irradiation of pacemakers is avoided, adequate monitoring is required during and after irradiation and the dose to the pacemaker generator should be kept below 2 Gy. Close follow-up with cardiologists and a pacemaker clinic is essential. Radiotherapy departments should have their own protocols in place for cancer patients with ICPs.

Key Words: Radiotherapy implanted cardiac pacemaker (ICP) – Case report – Case series and ionizing radiation.

Introduction

The number of patients world wide having pacemaker is increasing each day. The percentage of patients who have implanted cardiac pacemaker (ICP) and developing malignancy is also increasing with better diagnosis and better management of both cardiac and malignant diseases [1]. The expectations that having patients with ICP and need irradiation are quite high.

The usual indication for placement of an ICP is the prevention of bradycardia and treatment of atrioventricular block [2,3]. Since the first ICP in 1958, radiation oncologists have great fear from treating cancer patients with artificial pacemakers. In contrast to the old generation of ICPs which are resistant to radiation damage, the modern programmable ICPs are very sensitive to megavoltage radiation. Older generation ICPs tolerated doses from 100 to 460 Gy, well above the therapeutic radiotherapy dose for any cancer [3,4,5]. The complementary metal oxide semiconductors (CMOS) part of modern generation programmable pacemakers are affected by doses as low as 0.15 Gy [3]. Each new model in the market differs from older models in some way, either in design or structure or software program, thereby greatly influencing the radiosensitivity. There is no consistent way to predict how and at what radiation dose the device will fail. Despite the potential risk of catastrophic complications, the published clinical data are sparse regarding the safety of radiotherapy delivery to patients with pacemakers. Most of the clinical data case reports of single patient. There are no reports of large case series and as far as the authors are aware, there are no ongoing prospective studies. There are no uniform recommendations from the manufacturers [6-9].

The first patient treated with radiation therapy at King Fahd Medical City, Saudi Arabia was at 2006. By the end of 2008, three courses of radiation therapy were given to two cancer patients with ICPs.

In this article we are discussing the issues in radiotherapy planning of those patients, presenting a review literature about reported hazards of radiation on ICPs and recommending policy and procedure for treating such patients with radiotherapy.

Material and Methods

We reported our experience in delivering three radiotherapy courses for two cancer patients having
ICPs. The online Pub med and Cochrane database were searched for possible effect of radiotherapy on ICPs using key words; radiotherapy, ICPs, case report, case series and ionizing radiation induced damage.

Case 1:
A 76-year gentleman referred to radiation oncology department of King Fahad Medical City (KFMC) with recurrent non small cell lung cancer after right lower lobectomy done 1 year back without adjuvant treatment at that time as he was staged as stage I. The patient known to be cardiac with pacemaker (PM) dated 2 years before developing cancer. Computed tomography scan showed right lower lobe lung mass associated with multiple enlarged mediastinal LNs involving the subcarinal area. All metastatic work up was free. The patient received 3 cycles of chemotherapy (Taxotere and Carboplatinum) with no response so referred for radiotherapy.

Before radiotherapy, cardiac assessment showed complete left bundle branch block, prolonged QT wave, ejection fraction was 30%, impaired left ventricular relaxation with regional wall motion abnormality. The pacemaker function, type and the company specifications was revised with the cardiologist who accept treating patient with radiotherapy without shutting off the PM during radiotherapy fractions with weekly follow-up of the PM and the cardiac condition of the patient. Pulmonary function tests were within normal ranges.

Computed tomography simulation with slice thickness 5mm was fed in the treatment planning system (TPS). The target volume and organs at risk including the PM were delineated. Three dimensional conformal radiotherapy plan was done using Eclipse v8.0 TPS to deliver a 60 Gy over 30 fraction (fx) to the patient. Two phases were computed; phase 1 (34Gy/17fx by anterior and posterior fields) and phase 2 (26Gy/13fx anterior, right antero-lateral chest wall for palliating the metastasis to the ribs). The patient treated by Varian Linear accelerator series 2100C/D, Clinac DHX using 6MV. However, the radiation field was 10 cm away from the pacemaker. The dose to the pacemaker calculated by the treatment planning system (TPS). The target volume and organs at risk including the PM were delineated. The patient treated by Varian Linear accelerator series 2100C/D, Clinac DHX using 18MV. However, the radiation field was 10 cm away from the pacemaker. The dose to the pacemaker calculated by the treatment planning system with the maximum dose 0.4Gy for the whole course of radiation. The patient followed up during radiotherapy for fear of damage of the pacemaker. The patient was monitored during radiotherapy by daily ECG, weekly echo-cardiography and weekly checking of the pacemaker function. There was no pacemaker affection and no cardiac function affection reported during radiotherapy.

Case 2:
Thirty seven year-old woman presented to radiation oncology department at KFMC with locally advanced, recurrent and metastatic ovarian cancer. The patient was known to have ICP 3 years before development of cancer. The patient was refractory to 4 lines of chemotherapy. The patient received two courses of palliative radiotherapy.

Course 1:
The patient received whole abdomen radiotherapy 30 Gy/10fractions/2weeks. Computed tomography simulation with slice thickness 5mm was fed in the treatment planning system (TPS). The target volume and organs at risk including the PM were delineated. The patient treated by Varian Linear accelerator series 2100C/D, Clinac DHX using 18MV. However, the radiation field was 10 cm away from the pacemaker. The dose to the pacemaker calculated by the treatment planning system with the maximum dose 0.4Gy for the whole course of radiation. The patient followed up during radiotherapy for fear of damage of the pacemaker. The patient was monitored during radiotherapy by daily ECG, weekly echo-cardiography and weekly checking of the pacemaker function. There was no pacemaker affection and no cardiac function affection reported during radiotherapy.

Course 2:
The patient received palliative radiotherapy to right antero-lateral chest wall for palliating the metastasis to the ribs. The patient received 20 Gy/5fx/1week. The patient treated by Varian Linear accelerator series 2100C/D, Clinac DHX using 12 MeV electron beam. Applicator 20x20 with filed aperture 10x15 cm was used. The radiation field was 15 cm away from the pacemaker. The patient was monitored during radiotherapy by daily ECG and echo-cardiography after the end of radiotherapy course and then monthly for 6 months. There was no pacemaker affection and no cardiac function affection reported during radiotherapy and 6 months following radiation.
Results and Discussion

Overview of ICPs:

It has been estimated that up to 66% of cancer patients might require radiotherapy at some point during the course of their illness [2]. Radiotherapy will increasingly come across cancer patients with permanent cardiac pacemakers. The concept of cardiac pacemakers as potentially life saving devices emerged in 1950s. Artificial pacemakers are of three types’ external temporary pacemakers, permanent implantable cardiac pacemakers (ICP) and implantable cardioverter defibrillators (ICD).

The ICPs are commonly inserted into a subcutaneous pocket over the anterior chest wall over the pectoral muscles in the left infracavicular region. They vary in sophistication ranging from simple single-chamber pacemakers to demand-mode dual-chamber pacemakers. Implantable cardioverter defibrillators are much more sophisticated devices and more radiosensitive than ICPs [1,3].

Electromagnetic interference can mimic cardiac activity. Hence, any equipment with an electromagnetic source can potentially affect the functional and structural integrity ICPs. Electromagnetic sources affect the pulse generator as well as the sensors of the pacemakers [8,9]. The older generation of pacemakers, made up of bipolar semiconductor devices, are resistant to radiation damage at therapeutic doses of radiation. However, they are not in use any more and have now been completely replaced by programmable modern pacemakers [4,5]. The modern pacemakers with complementary metal-oxide semi-conductor (CMOS) circuitry are more sensitive than the older devices. The pacemaker malfunction during radiotherapy is a consequence of radiation damage to hardware and software. Various mechanisms such as ionization of semiconductor material, abnormal current flows, changes in threshold voltages and electrical interference from linear accelerator have been implicated [1,3,8,9]. The clinical consequences of electromagnetic interference could be transient such as dropped beats, transient inhibition or triggering of pacemakers. However, the consequences could be occasionally serious and permanent. For instance, severe circuitry damage can potentially lead to a major catastrophic failure of cardiac conduction system and ultimately death of the patient [2,8].

Effect of radiotherapy on PM patients:

A literature review for case reports of patients having ICPs that treated by radiation was performed to assess the risks that can be happened for those patients. There were no problems of the patients that treated with the early generation of PMs as mentioned before, on the other hand, the problems started with the new generation ICPs as summarized in Table (1).

The first reported radiation induced ICP failure was at 1982. A right sided breast cancer patient received postoperative radiotherapy. The ICP received 30-36 Gy. ECG showed a heart rate of 300 per min and the PM was immediately replaced. Analysis of the removed PM showed damage to the integrated circuit [10]. One year after that, Quertermous reported another PM failure. A patient with right-sided lung cancer with supra-clavicular nodal metastasis initially treated by 50.8 Gy in 27 fractions by anterior and posterior portals using a Varian Clinac-4 linear accelerator at an SSD of 100 cm. A boost of 16 Gy to the tumor in the upper right lobe as well as right supraclavicular area was added using the electron beam. The PM was not in the radiation portal during this treatment and the estimated scatter dose to the PM was only 1.25Gy. There was no effect on the ICP and no side effects discovered. On a subsequent occasion,
the patient needed right axillary irradiation. The PM was partly within the radiation portal during the second treatment. The patient became haemodynamically unstable after receiving 20Gy in 10 fractions over 2 weeks. An ECG revealed a chaotic rhythm and the PM was exchanged. A detailed examination of the PM by the manufacturer revealed radiation damage to the metal-oxide circuitry [11]. Pourhamidi et al. reported a case of mid thoracic oesophageal cancer with ICP treated with radiotherapy using 4 MeV photons and delivered 63Gy in 35 fractions to the tumor. The PM with CMOS circuitry was not in the centre of the field and the PM was estimated to have received only 15Gy in total. The pacemaker had been programmed at 833 ms (72.3/minute), at this time, it had an interval of 640 ms most of the time (93 per minute). The QRS was followed by pacemaker artifact. The pacemaker was analyzed in the manufacturer’s laboratories. Their studies found that the pacemaker’s large scale integrated circuit was damaged [12]. Lewin et al., presented a case of locally advanced soft tissue sarcoma of the right axilla. The case planned to receive preoperative radiotherapy 45Gy. The patient received 19.8Gy/11 fxs/2weeks; 1.8Gy/fxs using two parallel opposed fields only. After the 11th fraction, the patient was found to be tachycardic and the PM had to be exchanged. A detailed laboratory examination confirmed radiation induced PM failure [13]. Lee et al., presented two cases with ICPs. The first case was metastatic uterine carcinoma treated to the pelvis by 45Gy without any malfunction to the PM. Then the same patient received palliative irradiation to para-aortic area (39.6Gy/22fxs). Electrocardiography showed that the atrium was being paced at 300 beats per minute; there were ventricular spikes at 103 beats per minute. With application of the magnet over the pulse generator, the atrial output was inhibited and the ventricle was firing at a fixed rate of 120 beats per minute. For this pacemaker model, application of the magnet should result in atrio-ventricular pacing at a fixed rate of 90 beats per minute. The pacemaker could not be programmed. The pacemaker was replaced immediately and the patient’s symptoms were relieved. Analysis of the removed pulse generator by Intermedics Company indicated that the circuitry damage was consistent with exposure to ionizing radiation. The second case was 80 years old female with breast cancer treated following simple mastectomy to the chest wall. Thirty six Gy delivered by linear accelerator through five ports, one port encompassing the area occupied by the pacemaker. The ICP failed after the end of radiation with runaway rhythm. The pacemaker was immediately replaced. Analysis of the removed generator showed that there was damage to the large-scale integrated circuit [14].

A 48-year-old man with a multiprogrammable Intramedics 254-41 pacemaker was presented by Brooks et al. The patient was treated for inoperable lung cancer with a course of radiotherapy using cobalt machine (total 36.4Gy). Several weeks subsequent to his last radiation treatment, the patient presented to the emergency department with chest and abdominal pain, shortness of breath, hypotension and tachycardia. A paced tachycardia was noted and application of a magnet over the pacemaker completely inhibited its function, allowing a normal sinus rhythm to ensue and the patient’s symptoms to be relieved [15]. Mueller-Runkel et al. treated a patient with inoperable left lung cancer with radical radiation therapy. The patient received a cumulative dose of 64Gy to the tumor and a Cerrobend block mounted on a tray shielded the PM implanted on the left side. The patient was monitored during and after radiotherapy. They were unable to detect any malfunction of the CMOS PM, which received an estimated cumulative dose of 6.2Gy [16]. Raït et al. presented an 83-year-old woman with unipolar pacemaker (Pacesetter 2003S Solus). The patient was subsequently discovered to have papillary adenocarcinoma of the thyroid gland. The patient received radiotherapy by neutron with field designed so that the pulse generator in the left infraclavicular region was 2 cm from the nearest margin. Immediately after the fourth daily fraction of neutron radiation (1.2Gy per fraction, 4.8Gy cumulative dose to isocenter, 0.9Gy cumulative dose estimated to the device), tachycardia with a heart rate of 180 beats/min and a blood pressure of 90/60 mm Hg. This case illustrates the very sensitivity of PMs to neutron beam radiation [17]. Nibhanupudy used 6MV X-rays to treat a patient with left breast cancer. The patient had a PM implanted on the left chest wall 4 cm away from the radiation field. The PM received a cumulative dose of 1.6-1.8Gy without any interference in its function [18]. Riley et al. reported a bronchogenic carcinoma case with ICP. A treatment planning using noncoplanar beams and asymmetric fields was done followed by boost using intensity modulated radiotherapy to limit the radiation dose to the pacemaker. The delivered dose was verified utilizing five TLDs placed on the patient. Measurements of the daily dose from all of the treatment fields including portal imaging dose were taken. The PM received 5.6Gy of the total prescribed dose 63Gy without any PM dysfunction [19]. Li presented four patients implanted with PM. Among them, three had third-degree atrio-ventricular block...
(AVB) and one sick sinus syndrome (SSS). The diagnosis was esophageal carcinoma, non-Hodgkin’s lymphoma, non-small cell lung cancer and nasopharyngeal carcinoma. The radiation dose varied from 40 to 70Gy delivered by Co\textsuperscript{60} or 6MV linear accelerator. The patients monitored by electrocardiogram during radiation therapy. All patients completed the radiotherapy without complications and the function of ICPs were normal\cite{20}. Mitra et al. treated a case of cancer lung known to have ICP seven year before treatment. The radiation fields encompassed the tumor and superior mediastinum with prescribed dose 40Gy. The ICP came at the edge of the tumor with dose to ICP equals to 16.6Gy. The patient completed radiotherapy well\cite{21}. Zweng et al. reported a case of PM malfunctions occurred during radiation in a 76-year-old woman who was treated for inoperable esophageal cancer with a course of photon radiation. The estimated dose of pacemaker was the lowest in vivo dose ever reported (0.11Gy). So a direct radiation effect as cause for this malfunction appears to be improbable. Zweng et al. noted that the PM dysfunction was most likely induced by electromagnetic interference (EMI) during radiotherapy which can cause PM malfunction and the real reason of the device’s software failure remains unclear\cite{22}. Munshi et al. studied a case of breast cancer patient implemented with PM. The patient underwent breast conservative surgery and was planned for postoperative radiotherapy. X-rays (10 MV) were used in treatment planning with a 15 degree bilateral wedge for appropriate dose distribution. The PM received a 4.3Gy of 50.4Gy total prescribed dose. The entrance dose was measured using TLD and it was 15.37cGy. The patient followed up during radiation and for 10 months after end of treatment with the PM functioning normally\cite{23}.

Our reported cases showed no malfunction of ICPs during and after radiation for 6 months. The first case irradiated with 60Gy to the chest. The precautions of treatment planning and dosimetric checks were performed like Riley and Munchi precautions\cite{19,23}. The maximum calculated dose to the pacemaker was 1.16Gy. The other case received 2 courses of radiotherapy; the 1\textsuperscript{st} course showed calculated dose 0.4Gy to PM and the dose was not measured because the treatment fields are 10cm away from the PM. The 2\textsuperscript{nd} course was delivered by electron beam and the field of radiation was 15 cm away from PM. The dose to PM again not measured as it is far away from the field of radiation. Our patients were followed up closely even with expected small doses to the ICPs for fear of EMI effects as reported by Zweng et al. at 0.11 Gy level\cite{22}.

Table (1): Case reports of cancer patients having ICPs received radiation.

<table>
<thead>
<tr>
<th>Author</th>
<th>Diagnosis/ radiotherapy course</th>
<th>Pts no</th>
<th>Dose in Gy</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katzenberg, 1982\cite{10}</td>
<td>Breast cancer</td>
<td>1</td>
<td>30-36</td>
<td>&lt;36</td>
</tr>
<tr>
<td>Quertermous, 1983\cite{11}</td>
<td>Lung cancer</td>
<td>1</td>
<td>50.8</td>
<td>1.25 No failure</td>
</tr>
<tr>
<td>Course 1</td>
<td>Lung+ supraclav RT</td>
<td>20</td>
<td>2.3-8.9</td>
<td>Circuity failure</td>
</tr>
<tr>
<td>Course 2</td>
<td>Axilla RT</td>
<td>20</td>
<td>15</td>
<td>PM damage</td>
</tr>
<tr>
<td>Pourhamidi, 1983\cite{12}</td>
<td>Esophagus (mid 1/3)</td>
<td>1</td>
<td>19.8</td>
<td>19.8 ICP failure</td>
</tr>
<tr>
<td>Lewin, 1984\cite{13}</td>
<td>Haemangioepericytoma</td>
<td>1</td>
<td>19.8</td>
<td>19.8 ICP failure</td>
</tr>
<tr>
<td>Lee, 1986\cite{14}</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pt no 1</td>
<td>Uterine carcinoma</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course 1</td>
<td>Pelvis RT</td>
<td>45</td>
<td></td>
<td>No failure</td>
</tr>
<tr>
<td>Course 2</td>
<td>Upper abdomen RT</td>
<td>39.6</td>
<td></td>
<td>ICP failure</td>
</tr>
<tr>
<td>Pt no 2</td>
<td>Breast cancer</td>
<td>36</td>
<td></td>
<td>PM failed</td>
</tr>
<tr>
<td>Brooks, 1988\cite{15}</td>
<td>Lung cancer</td>
<td>1</td>
<td>35</td>
<td>&lt;35 ICP failure</td>
</tr>
<tr>
<td>Mueller-Runkel, 1990\cite{16}</td>
<td>Lung cancer</td>
<td>1</td>
<td>64</td>
<td>6.2 No failure</td>
</tr>
<tr>
<td>Raitt, 1994\cite{17}</td>
<td>Thyroid cancer</td>
<td>1</td>
<td>4.8 neutron</td>
<td>0.9 ICP failure</td>
</tr>
<tr>
<td>Nibhanupudy, 2001\cite{18}</td>
<td>Breast cancer</td>
<td>1</td>
<td>50</td>
<td>1.6-1.8 No failure</td>
</tr>
<tr>
<td>Riley, 2004\cite{19}</td>
<td>Lung cancer</td>
<td>1</td>
<td>63</td>
<td>5.6 No failure</td>
</tr>
<tr>
<td>Li, 2004\cite{20}</td>
<td>Eso-NPx-NHL-SCLC</td>
<td>4</td>
<td>40-70</td>
<td>No failure</td>
</tr>
<tr>
<td>Mitra, 2006\cite{21}</td>
<td>Lung cancer</td>
<td>1</td>
<td>40</td>
<td>16.6 No failure</td>
</tr>
<tr>
<td>Zweng, 2008\cite{22}</td>
<td>Oesophagus carcinoma</td>
<td>1</td>
<td>50</td>
<td>0.11 Failed</td>
</tr>
<tr>
<td>Munshi, 2008\cite{23}</td>
<td>Breast cancer</td>
<td>1</td>
<td>50.4</td>
<td>4.3 No failure</td>
</tr>
</tbody>
</table>

The reviewed case reports showed wide variation of radiotherapy effects on ICPs, so there is a need of developing recommendations for the use of radiation in those patients. At present there are no uniform recommendations from the manufacturers and the available recommendations are unreliable. The only available recommendations are ASTRO recommendations [7] and the AAPM published in 1994, of which there is no recent official updated report [6]. They recommended that maximum dose to the pacemaker be limited below 2Gy. However, no recommendation for the effect of dose rate has been made. Until clear recommendations become available, it is the responsibility of the individual radiotherapy departments to identify and develop formal protocols for cancer patients with pacemakers especially in the planning and delivery of radiotherapy. The St Jude’s pacemaker guidelines published in June 1998 state that 2Gy is enough to damage CMOS circuitry. They recommend keeping the ICP outside radiation field [24]. Medtronic guidelines recommend a total allowable dose to the pacemaker up to 5Gy and they also require generator to be moved outside the field [25]. Guidant guidelines have recommended that there is "no safe dose" which can be recommended as total allowable dose [26].

Conclusion and recommendations:

Modern multi-programmable pacemakers are very sensitive to therapeutic megavoltage irradiation. There is no safe radiation threshold for megavoltage radiation. Even when the pacemaker is not in a radiation field, scatter radiation has the potential to cause pacemaker malfunction. The electromagnetic inference can cause ICP malfunction with very low radiation level. However, radiotherapy is not absolutely contraindicated in cancer patients with ICPs [2,6,7].

There will be an increasing number of cancer patients with pacemakers in future and irradiation of the patients needs to be done safely. Radiotherapy departments should have protocols for treating cancer patients with pacemakers. Based on the literature review, we recommend that the radiotherapy departments take the following recommendations to minimize the risk of pacemaker malfunction during delivery of radiotherapy. These recommendations are to be used as general guidelines only and each patient needs to have individualized care in consultation with the relevant cardiologist and a pacemaker clinic. We classified the recommendations into two categories; clinical and dosimetric recommendations.

I- Clinical recommendations:
1- All radiotherapy staff should be educated about the potential risks involved in irradiating patient with ICP.
2- Full assessment of patients with ICP is mandatory and functional integrity of the PM at the most recent visit to the PM clinic should be ascertained.
3- Follow-up with the cardiologist and the PM clinic is essential before, during and after treatment.
4- Baseline ECG and echocardiography should be obtained in all patients with PMs to assess the PM dependency.
5- Treat with close PM if available in non PM dependent patients.
6- Close monitoring of ICP and the patient vital signs during the radiotherapy session.
7- In PM dependent patients, where the PM would receive a significant dose, one option is to irradiate with a backup temporary external PM, which is kept well away from the radiation field.
8- In patients who are not PM dependent, if the PM irradiation could not be avoided, the PM could be sacrificed after consultation with the cardiologist and the PM could be replaced after the completion of radiotherapy.
9- Following the completion of radiotherapy, all patients should be followed by the PM clinic, and the cardiologist for fear of late damage.
10- The patients should also be educated about the risks of late malfunction of PMs due to latent radiation damage so that they can seek immediate medical attention in case of an emergency.

II- Dosimetry recommendations:
1- The ICP model and the manufacturers’ recommendations regarding safe radiation doses for that particular model of PM should be ascertained.
2- Never treat a PM patient with a betatron device.
3- The use of high precision dose delivery techniques such as IMRT and stereotactic treatment may be of potential benefit in relation to reducing the dose to a PM.
4- The PM could be considered like an ‘organ at risk’ with the usual planning considerations.
5- It is essential either to measure or calculate the dose of radiation received by the PM. The total dose to the PM can be estimated by diode, ionization chamber or by TLD measurements.
6- Keep the total dose received by PM as low as possible or at least less than 2Gy using appropriate radiation quality, energy and modality.
with suitable field angles and different beam modifiers.
7- PM should not be placed in the direct field.
8- Keep a 3 cm margin of PM away from the radiation beam edge.
9- For patients that the PM can receive dose >2Gy consideration should be given to surgically shifting the PM to a region of less radiation dose.

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