The standard SARRP

The current SARRP system (http://www.xstrahl.com/sarrp.htm) represents remarkable improvement in animal treatment over standard animal irradiating systems. This technology was originally developed by John Wong and colleagues at John Hopkins[1,2,3]. The immediate obvious advantage is the addition of volumetric imaging at treatment time. Volumetric imaging of animals of very high resolution has been possible for quite some time on stand-alone imaging machines (e.g. high field magnetic resonance imaging (MRI) animal scanners, Micro PET and MicroCT scanners. Previously researchers have tried to 'target' on the resultant MRI produced images and then set up on the treatment machine by transferring the alignment. In practice relatively crude collimators were prepared to suit the irradiation site, which was often inferred from external anatomic details. Although this may be adequate for e.g. xenografts or limb tumours, when it comes to orthotopic tumours on internal sites, this becomes an extremely challenging task, requiring excellent mechanical co-registration. For some well immobilized anatomic sites (such as the brain) this method can be successfully applied. Even in the case of precisely co-registered imaging and treatment machines (using transferable fixation devices) the practical set-up variations prevent a repeatable alignment of better than 3 mm or so. This is also a best case scenario and only attainable in situations in which the treatment site is unusually easy to immobilize and does not vary over the treatment course.

For other sites with inter and intra-fraction tumour motion and tumours that change over the treatment course this level of accuracy cannot be attained. In fact due to the lack of treatment time imaging in many cases the alignment accuracy is essentially unknown but can be estimated at several millimetres. This means the treatment areas have to be enlarged encompassing large (compared to the tumour) volumes of normal tissue solely to cover the alignment certainly. The damage this causes to normal tissue effectively rules out many treatments and massively complicates analysis of the effectiveness and consequences of all radiation based treatments. This is similar problem to that which faced clinical radiotherapy about a decade or two ago.

A major step forward occurred in clinical radiotherapy with the advent of cone beam computer tomography (CBCT). This is similar to normal CT but with the crucial advantage that it occurs immediately before treatment. Clinically this not only led to improved set-up but revealed previously unknown tumour motions, leading to research into image guided and adaptive radiotherapy.

The SARRP system also incorporates CBCT imaging which also allows excellent set-up accuracy. Previous research has estimated this to be sub mm (~0.2) in well immobilized sites. Such accuracy is achieved through volumetric imaging and computational registration to reference templates. Naturally to make such shifts manually would be very difficult hence the treatment platform sits on a motorized three axis platform which can make shifts to a far greater accuracy (~15 μm) than the uncertainty in the image registration. Compared to the previous set up accuracy and taking into effect that in mouse irradiation the targeted organ may have dimensions of <1 mm in one dimension this is a game changing improvement.

The similar absorption of X-rays in differing soft tissues limits all X-ray attenuation based imaging systems such as standard CT. The problems are exacerbated in higher energy X-ray systems. For the case of SARRP the CBCT X-ray source is generally operated at 100kV which is high compared to the 20kV or so often seen in animal micro CT. This gives the considerable advantage of lower imaging dose but means there is a risk some organs will not be visible on the CBCT reconstruction. In this case there is little alternative but to use other imaging modalities to identify and delineate the organ.

In order to use other modalities but retain the advantage of image guided radiotherapy some form of matching is required. The SARRP system provides this by incorporating a multi-modality image registration tool. This allows the manual or automatic registration of an MRI image to the treatment-time CBCT reconstruction. This then allows targeting of the organ only visible on MRI. The relative location of the organ invisible on the CBCT can then be saved. Later the CBCT can be automatically aligned to this reference point. The work flow will be minimally altered by this addition. It will however require the extra scans on the 'other' modality, initial registration and possibly later checking of the registration validity.

When it comes to radiation delivery there are several interesting aspects to the SARRP system. The first is the X-ray source. The same X-ray tube is used for imaging and treatment. For imaging the smaller the source size the better as this reduces blurring and effects caused by the penumbra on the projected image. For treatment higher powers are needed which cannot be achieved with a small source size on standard anodes. The solution to the dilemma is to use a dual filament tube allowing operation in either fine focus low power (0.4 mm at 640 W) mode or broad beam high power mode (3 mm at 3000 W).

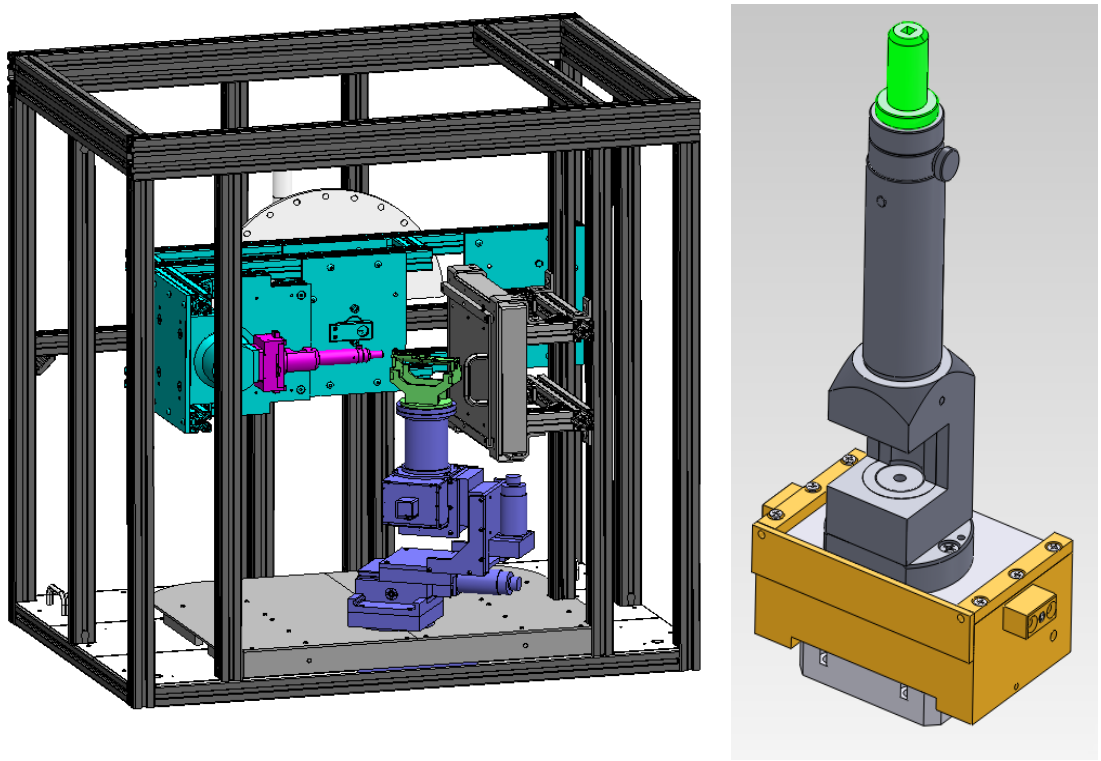
For imaging and treatment the operating voltage is very different. For imaging, there is a trade-off between contrast and dose, the optimum voltage coming out at about 100 keV. For therapy the higher the energy the better as this decreases the dose rate fall-off in the body. To take all these factors into account and allow customization for imaging the SARRP is powered by a high power tube supply adjustable from 50-225 kV. The therapeutic dose is delivered at 220 kV.

When in treatment mode the X-ray beam emanating from the tube is defined by a bespoke collimator. The collimator is composed of a thick metal tube ending in several interchangeable apertures ranging from 5 x 5 mm squares down to 0.5 mm diameter circles. The final exit of the aperture is located to terminate very close to the isocentre (<6 cm). This means that the geometric penumbra is reduced to a minimum (0.6 mm with the treatment beam).

The high operating voltage affords a reasonable fall-off with depth. However to treat deep tumours the radiation needs to be applied from several directions. This then allows the entrance dose to be spread out resulting in minimal damage to any normal tissue preceding the tumour in the beam's direction. However it would be difficult and very slow if set up was required at each treatment angle for each treatment fraction. This can be avoided if the treatment beam is mounted on a stable and well-characterized mechanical gantry. SARRP is equipped with such a gantry, thus only one set up is needed per treatment fraction. The gantry can be rotated from -10 to 120 degrees (increasing anti-clockwise and defining the highest point of the tube as 0 degrees).

Kilovolt photon radiation is not as penetrating as the more clinically common Megavolt radiation. However this is mostly offset by the shallower tumours that are treated in animal radiotherapy. To achieve treatments with SARRP similar to the precise tumour conforming treatments seen clinically (when using techniques such as intensity modulated radiotherapy (IMRT)) many treatment beam angles would be required. Whilst this is indeed possible there is actually no need to limit the number of beam angles and thus dose spreading. The dose can be applied whilst sweeping the beam across the full gantry range. If applied to a rotating 'patient' this comes close to a perfect 'treating sphere'. This is possible on SARRP as the treatment can be active no matter what the motion of the patient and gantry (excepting motions that would result in collisions). In practice such complex rotation is unlikely as it may induce slight errors in the targeting. However on a static tumour the degrees of freedom in radiation delivery SARRP has are sufficient to allow excellent dosimetric patterns far in excess of what was previously possible.

In summary the SARRP system allows precise image guided radiotherapy. It allows a far more definite knowledge of the radiation dose applied to a subject. When coupled with its high accuracy and ability to spread out the normal tissue dose this ultimately provides far better isolation of tumour dose response.



CAD models of the whole SARRP (with the gantry shown in aqua marine, the treatment head in pink, the treatment table in green and the alignment translator in purple) and the treatment head composed of the beam collimator shown in grey and final aperture shown in green.

Photograph of Sarrp with the treatment head attached and the gantry in the vertical position.

References

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