Equipment selection, acceptance testing, commissioning and QA/QC
Aims

- To appreciate the additional equipment and resources required in order to
  - Transition from basic CRT (2D) to 3D CRT
  - Sustain a quality 3D CRT program

Terminology from Table 1 (1588)
In 2D one often works with separate systems and a degree of manual transfer and/or communication between duty stations in terms of radiotherapy workflow. One of the most important priorities in specifying and commissioning equipment when going from 2D to 3D is the networking of all components, both data and imaging. The TPS or the R&V system forms the “heart” and should comply with DICOM and HL7 standards in order to obtain efficient communication between the various imaging, data and delivery stations. HL7 compliance is necessary if there is exchange of data with a hospital information system. In parallel to this, additional resources are needed in order to ensure that all components function according to the desirable workflow. An overall system manager for the radiation oncology Intranet should be designated and ensure that there is adequate firewall protection from all other networks.
Specific Learning Objectives

• Immobilisation
  – Identify the site specific immobilisation and positioning devices required for the transition. Distinguish between the devices and how they are to be used for each site (head and neck, breast, pelvic, abdomen, lung/chest).
  – Associate for each device how it will be referenced to the initial imaging and located for reproducible daily setup.
  – Prepare/suggest an experiment to measure setup margin with such a device.

Under item 1 we assume that there is an understanding of the common cancers requiring 3D CRT within the specific audience. This will drive the necessity and priority for more or less discussion around the different systems. Often home-made devices can be developed in resource constrained environments in order to avoid ongoing delivery costs for consumables. There is a distinct advantage to reusable materials in a resource constrained environment.

Note that all devices should have a system of referencing so that patient position can be reproduced and clearly patient safety and comfort are important. It is a good idea to try and measure geometrical setup margin when introducing new devices as it assists in developing Institutional PTVs.
Specific Learning Objectives

• Immobilisation
  – Design and/or modify devices for specific cases, e.g. decubitus, claustrophobic patients, etc
Two head and neck systems are shown here and it can be seen that they are both simple and effective for claustrophobic or unco-operative patients. Often quality planning is most dependent on the neck position so a range of head rests (cushions) should be available. Depending on the workload, identical clearly-marked sets should be available at all imaging and treatment duty stations. In both these cases referencing is done on the system itself. For instance, the system on the right has 3 crosses marked on the arch which would provide the initial setup to the laser system. Individual patients are then setup using couch movements (lateral, longitudinal and vertically from the arch reference. The arch is movable longitudinally along the base plate and positioned relative to the additional immobilisation aid used – a nasium is shown here. This could then equivalently be used with a biteblock or a chin mould, for instance.
These are other possible, more advanced head and neck systems showing use with and without shoulder localisation. The system on the right is a locally developed system that centers and locates to the table top centre-spine. The system can be adapted to any mask system, it includes the facility for including forming over the shoulders, it can accept a body cast (on the grey area) and it has hand grips to secure shoulder position. Both systems will use a combination of the couch localiser and transcribed markings on the patient’s mask as referencing.

IAEA Video of immobilisation in head and neck + CD.
Immobilisation of the chest normally requires a system wherein the arms are removed from any possible beam entry position so they are normally placed above the head. The head is normally extended to ensure it is removed from the field. To avoid patient rotation, reference marks are extended along the anatomical midline as well as on both sides. A body cast may be used and often knee positioners also assist in anti-rotation and comfort. From the protocol lecture (section 5) one needs to scan the whole volume of an organ for which volume dose evaluation is ultimately needed. In these cases it is important to ensure that the patient is immobilized along that whole volume, e.g. if the target is the upper third oesophagus, one needs to scan from below the level of the diaphragm in order to evaluate lung dose.
Breast is extremely difficult to immobilise and therefore most devices available are purely for positioning purposes. A CT bore cannot accept a tilt of more than 20 degrees and this limits planning of tangential breast ports without a collimator rotation. In 2D breast simulation it is common to use high board tilt angles to treat the chest wall with no collimator swivel (BIR PTV document, 2003). Using a collimator angle in the breast fields makes the matching of supraclavicular gland fields more complex in advanced cases. Should a higher tilt be needed to reduce lung toxicity and avoid excessive beam shaping, it will not be possible to scan up to the supra-clavicular volume. Breast patients rotate daily both laterally and cranio-caudally, so skin markings are highly recommended and a simple back-pointer (which defines beam exit) on the treatment unit is also a valuable setup aid if daily portal imaging is not planned.
When performing CT scanning for breast planning, it is important to remember that it is not possible to see all surgical clips, scars and drain sites unless very thin slices are taken and therefore attention is needed for the clinician to identify such regions with radiopaque markers prior to scanning. This simulation film shows an example of how a scar (wired anteriorly) is not always indicative of the location of the tumour bed and care should be taken of boost volumes. Remember that skin marks remain highly beneficial to aid in daily setup and that larger setup tolerances must be accepted, unlike other sites requiring highly conformal RT.
The CIVCO video may be helpful here.

There are various solutions available on the market for immobilisation of almost all areas of the body. It is worth researching the different options and prioritising the most critical disease sites within the resources available. This slide shows a Vac-lok (TM, CIVCO) system to cast the whole body or part thereof. This can also be done with polyurethane chemicals, which provide a cheaper solution but the cast is then not reusable.

Also shown is a prone system specifically to remove small bowel from the field. Similar stabilisation can be achieved with pillows under the chest and pelvic.
The CIVCO video may be helpful here.

This is the Knee and Feet Fix (TM, CIVCO) system for preventing anti-rotation in supine pelvic patients, which locates to the tabletop. The couch locater shown here was manufactured in a hospital workshop (Johannesburg, South Africa) and similar locaters were made for the simulator, CT scanner and other treatment units on site, which all have different couches. The patient can then be re-positioned daily in nearly the same position along the tabletop.
This slide shows an ‘extreme’ case of immobilisation in which a patient was expected to remain comfortable for an extended period of time for a SBRT procedure. This demonstrates that combinations of systems can also be used depending on their availability and the degree of immobilisation required.
Assume that section 1.5 on CT protocols has been covered.

Suggest the use of CAPCA/AAPM protocols for QA/QC.

CT scanners are often available in Radiology departments however, there are some additional features which are necessary to adapt them for use in RO treatment planning (listed). Clearly there is an advantage for a RO department to have a dedicated CT scanner especially if there is no conventional simulator. Most QA/QC protocols for the CT scanner recommend the same tests be performed as in Radiology to ensure adequate image quality. In addition, other tests need to be done that are more associated with the additional RO features.

Virtual simulation (VS) workstations are optional if a 3D treatment planning system is available, however management of workload and workflow are often what defines how much field localisation takes place on a dedicated VS workstation.

Large bore scanners are more expensive to maintain and do not increase the FOV compared to standard scanners. The additional resources would need to be weighed against the benefit of an additional 5 cm radius in the aperture, which increases manoeuvrability with large patients and/or immobilisation devices that cannot fit through a standard aperture size.
ICTP (Oelfke and Hunt)

CT technology has changed dramatically since its inception clinically, procedures are becoming faster and data processing speeds increase continually. This has been driven primarily by our imaging colleagues. For RO, whereas 3D CRT was originally accustomed to organ motion being included in CT images, we now are able to take snapshots of patients in order to better track and refine our knowledge of organ motion (4D). What one needs to remember is that fast CT scanning produces a snapshot of patient position and one needs to appreciate what changes there could be in the internal anatomy intra- and inter-fraction.
ICTP (Oelfke and Hunt)

Spatial resolution, contrast resolution and noise are standard QC parameters measured for all CT scanners and their consistency over time is obviously important to image quality.
ICTP (Oelfke and Hunt)

Artefacts on the other hand, can clearly alter what we are looking at in terms of target or OAR volumes and some may influence electron density values, e.g. teeth and prostheses.
ICTP (Oelfke and Hunt)

Reconstruction techniques will also influence visibility of targets during segmentation.
ICTP (Oelfke and Hunt)

This slide illustrates the partial volume effect in which an inhomogeneity is perceived differently depending on where it is located relative to the slice reconstruction.
This slide shows the partial volume effect from a sequential vs. a spiral scan and the differences in the multi-planar reconstructed views.
The CT number to electron density conversion is important to the TPS dose calculation and often the relationship has to be measured and entered on site. Basic checking of CT number is often built into the CT daily warm-up procedure but additional checks should be done regularly. Often the CT is supplied with a test phantom for the field service engineers to use and this has various inhomogeneities embedded into it. Alternatively, simpler systems can be produced on site using commonly available materials. Many QC protocols exist for CT scanners used in virtual simulation and/or 3D TP, e.g. IAEA, CAPCA, AAPM.
Specific objectives

• TPS
  – Working knowledge of TRS 430
  – Appreciation of the importance of networking to:
    • CT (MR, PET)
    • R&V
    • Treatment units (DRRs for imaging purposes)
    • Virtual simulation workstation?
  – Ongoing end to end testing
  – Ongoing impact of upgrades to all networked systems, which have to be co-ordinated to ensure sustainable functionality

A very comprehensive presentation [ICTP (Vatnitsky)] covers the whole of TRS 430. Chapter 8 JVD book.
Several very comprehensive documents exist for testing the integrity of treatment planning systems and their networked components. This is an extensive process and although silver data for most modalities is often available on new systems, this would still need to be checked for suitability and accuracy. Suppliers’ requirements for acceptance testing of a TPS are often very limited and it is highly recommended that one of the International documents be scrutinised for full testing and commissioning.
As with every other system in RO, a TPS also needs to be subject to ongoing testing and preferably, external auditing using end to end testing if available.
A good idea is to always have a feel for the accuracy of the TPS in areas in which most algorithms are known to be less accurate. These are shown in this slide. This is important for instance in searching for areas of minimum dose in superficial tumours which extend into the buildup region, where errors of up to 50% in planning algorithms are common.
Specific objectives

• LINAC/cobalt
  – Realise that all treatment unit ATP, commissioning and ongoing QA/QC are fundamentally the same for 2D and 3D CRT
  – In addition data and image connectivity issues are more critical when performing 3D CRT
  – IAEA Setting up a radiotherapy programme, 2008
    • Appendix VII specifically addresses cobalt vs. Linac

Here the issues of costing, existing equipment, technical maintenance capability, etc are going to drive the conversation. Refer to the IAEA Setting up a radiotherapy programme, 2008 (new 1040 Tecdoc).
Specific objectives

• MLC
  – Detailed specification of an integrated MLC is unnecessary since they are unique to the external beam unit on offer (unless it is an add-on SRT system). This would also hold true for standard teletherapy units that are upgraded to MLC. The only decision is the number of leaves!

ICTP (Amols) does a good comparison between vendors in terms of capabilities and design.
Specific objectives

• MLC
  – Understand that MLC necessitates a networked R&V system
  – Know the limitations of each system, how they impact on QC and data transfer issues.
  – Differentiate between static conventional use for CRT only vs dynamic use (IMRT). Often this is an option and could result in an expensive upgrade for users who progress to IMRT!

There is good ASTRO documentation from 2008 giving vendor-specific testing for MLC.
Integrated MLC designs differ in position, orientation, number of leaves, leaf shape and features. It is clearly critical that the TPS and R&V can correctly capture the physical characteristics and limitations of each system.
This slide is hidden and may be used to show an overview of the head design with a conventional MLC.
Vendor pictures of MLC design and capability.
These slides show MLC constraints w.r.t. closing, interdigitation, asymmetry and interleaf transmission, all associated with design. These design features should be incorporated into the treatment planning system.
For conventional 1 cm leaves, there are also often constraints in terms of adequate curvature in highly-conformal beams, matching of fields using non-focussed edges (penumbra), ability to simply provide island blocking, soft/motorised wedging in the leaf direction and optimise leaf position without adequate computerised optimisation. This complicates the use of MLC in a pure 2D setting and may not justify its implementation in terms of resources as a purely CRT tool without a transition to IMRT.

I will try and find better pictures here - DVDM
MLC QA/QC

Table 1: Quality Control Tests for Multileaf collimators

<table>
<thead>
<tr>
<th>Designator</th>
<th>Test</th>
<th>Tolerance</th>
<th>Action Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient-specific</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FM1</td>
<td>Verification of transferred data vs printed template</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>PM2</td>
<td>Daily verification of correct data</td>
<td>Reproducibility</td>
<td></td>
</tr>
<tr>
<td>PM3</td>
<td>Verification of record &amp; verify programming</td>
<td>Reproducibility</td>
<td></td>
</tr>
<tr>
<td>Monthly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MM1</td>
<td>Digitizer check (if used)</td>
<td>Functional</td>
<td></td>
</tr>
<tr>
<td>MM2</td>
<td>Light and radiation field coincidence</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MM3</td>
<td>Leaf positions for standard field template</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MM4</td>
<td>Electron field interlocks</td>
<td>Functional</td>
<td></td>
</tr>
<tr>
<td>MM5*</td>
<td>Leaf alignment</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MM6</td>
<td>Records</td>
<td>Complete</td>
<td></td>
</tr>
<tr>
<td>Yearly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AM1</td>
<td>Leaf transmission (all energies)</td>
<td>Reproducibility</td>
<td></td>
</tr>
<tr>
<td>AM2</td>
<td>Leakage between leaves (all energies)</td>
<td>Reproducibility</td>
<td></td>
</tr>
<tr>
<td>AM3*</td>
<td>Transmission through abutting leaves</td>
<td>Reproducibility</td>
<td></td>
</tr>
<tr>
<td>AM4</td>
<td>Stability with gantry rotation</td>
<td>Reproducibility</td>
<td></td>
</tr>
<tr>
<td>AM5</td>
<td>Alignment with jaws</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>AM6</td>
<td>Independent quality control review</td>
<td>Complete</td>
<td></td>
</tr>
</tbody>
</table>

*T may not apply to all MLC designs.

Tolerances and action levels are specified in millimeters unless otherwise stated.

CAPCA/AAPM TG 142

MLC increases the maintenance and QC demands on a system owing to increased complexity. QC protocols are different for the different vendor designs and also differ w.r.t. to use in static, dynamic and SRT mode. This is a snapshot from the CAPCA recommendations. Thought needs to be given to the additional quality control tools that would be required to support and MLC.
Various QC protocols exist (CAPCA, AAPM, etc).

The method of treatment verification is again dependent on the most common cases needing to be imaged and the networking in place to have images approved by a physician. Clear roles and responsibilities need to be developed to ensure that imaging is optimised according to departmental protocols.

Specific objectives

• In-room imaging (selection, ATP, commissioning, QA/QC)
  – Describe the various systems that can be used
  – Choose the appropriate type of on-treatment imaging method based on the important sites and techniques, e.g. field ports, positioning verification, anatomical landmarks (bony/soft tissue).
The simplest form of imaging is the use of film, as is often used in 2D for comparison with a simulation image. The kV and MV images are often complementary, e.g. the breast and chest wall. Most departments who have imaged this way for 2D are then accustomed to offline approval of images.
The most natural progression from simulation and film is to DRR and EPID respectively. EPIDs are nowadays also capable of producing MV CT images and this improves on planar imaging when cross-sectional anatomy is more useful to ensure correct field placement.
This slide shows the generic workflow when introducing EPID.
<table>
<thead>
<tr>
<th>Tests</th>
<th>Method/Tools</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical safety</td>
<td>Inspection, ODI, collision interlock</td>
<td>No accidental crash. 2mm physical alignment.</td>
</tr>
<tr>
<td>Electrical safety</td>
<td>Inspection, grounding &amp; insulation tests</td>
<td>IEC standards. No exposed connections/wire.</td>
</tr>
<tr>
<td>Calibration</td>
<td>Per vendor procedures for energy &amp; field size</td>
<td>Flat field, dark current image, correction factors</td>
</tr>
<tr>
<td>Dose control</td>
<td>Verify correct beam termination with dose</td>
<td>Preset dose control functions.</td>
</tr>
<tr>
<td>Image quality</td>
<td>Las Vegas Phantom, etc. Test each energy</td>
<td>1% Contrast. 2-3mm spatial resolution.</td>
</tr>
<tr>
<td>Functional software features</td>
<td>Functionality tests. Measurement accuracy tests with known error conditions &amp; verify system detection, ...</td>
<td>Reported measurement within 3mm or 2 deg. Edge detection matches field boundary</td>
</tr>
</tbody>
</table>

Again various QA/QC protocols exist for portal imaging and it is clearly more resource intensive than film.
A different approach is the use of CT scanning prior to treatment by swinging the couch. This is not a pre-requisite to CRT but can be considered for IMRT/IGRT.
ICTP (Jaffray)

This slide show an example of integrated kV imaging devices for portal verification imaging and/or adaptive RT.
ICTP (Jaffray)

This shows an example of QC performed daily on a kV imaging system used for IGRT. It can be seen that the tolerances are tight and will impact on maintenance - careful consideration of resources is needed in centres where the devices will not be used routinely.
Specific objectives

• R&V
  – Awareness of function and role to record dose and parameters (logfiles), as well as to verify that treatment parameters are the same.
  – Realise the importance of hierarchical security rights and good system management to ensure correctness of workflow according to local procedures, e.g. approval of prescription prior to allowing treatment.

See IAEA Setting up a radiotherapy programme, 2008 (new Tecdoc 1040).
Specific objectives

• R&V
  – To appreciate the value in terms of HL7 compliance to Hospital Information systems
  – Systems can also include ID and setup photos to reduce mis-identification and transcription respectively
  – To appreciate the value as part of the DICOM compliant image database.

See IAEA Setting up a radiotherapy programme, 2008 (new Tecdoc 1040).
R&V

- It is important to realise that R&V systems are fundamentally patient databases and that they can also be used therefore to extract:
  - Statistical data, e.g. age, diagnosis, etc
  - Workload data
  - QA tools (interrogation of logfiles)
Error analysis with manual data entry and data transfer problems ICTP (Hunt)

It is important to realise the impact that R&V systems have on safety. This slide shows the reduction in clinical incidents by introducing a networked R&V system and in so doing, avoiding manual data entry.
As per all computer networks which store critical data, a comprehensive QC program is necessary for an integrated R&V system. This is an example of a document from CAPCA. It may be beneficial for the hospital IT division to participate in such a program.
Specific objectives

• Dosimetry equipment
  – Describe the requirements for:
    • the automatic beam acquisition system for TPS data, including TPS format, ionisation chambers, etc
    • Ancillary QC test objects for the CT, portal imaging system, MLC, end to end test objects.
    • In-vivo dosimetry system based on the techniques planned
Key to 3D CRT is the acquisition of beam data for the TPS. Instructions from the TPS vendor are comprehensive and give details of all the requirements for their particular system. Silver data is often available for comparison and will assist in detecting large errors.
Depending on the modalities to be commissioned, different ionisation chambers are recommended. Often ionisation chambers used for calibration can also be used for relative dosimetry, provided that they are waterproof!
For commissioning of small fields and measurements in steep dose gradients, it is worthwhile to investigate small volume detectors in order to improve accuracy of data. It is worthwhile to investigate recent references on small field dosimetry as there are many challenges in this field.
Small fields

- Detector size must be small enough

Eduard Gershkevitsh
End to end testing of all systems and particularly of highly complex, networked systems is an important QA tool. This type of test ensures adequate and consistent transfer of data and images between the various workstations and provides a means of conducting an internal audit of clinical practice.
As per any other RO equipment, the suite of dosimetry equipment also requires a QA program, which is not limited to the maintenance of traceable calibrated equipment for absolute dosimetry including barometers and thermometers. Also included in routine testing should be all relative dosimetry equipment e.g. in-vivo dosimetry, ionisation chambers, film dosimetry, detector arrays, phantom materials, etc. Again, recommendations are available like the CAPCA document shown in this slide.
Specific objectives

• Data transfer
  – Appreciate that electronic data transfer should be DICOM compliant to avoid middleware or manual data transfer
    • DICOM (imaging systems)
    • DICOM RT (structure, plan, object)
This slide shows the complexity of highly developed RT networks. For centres who wish to progress from 2D to 3D CRT it is highly recommended that a physical layout of their duty stations indicating patient and staff workflow is produced. From this, the locations of connectivity ports, hubs, protocols and data transfer directions can be mapped and used in the overall specification for equipment.
Maintenance

- Availability of on-site immediate maintenance is ideal
- Comprehensive maintenance contracts need to include requirements for hardware and software, upgrades and updates
- All upgrades and updates must be compatible with all systems on the network
- Licenses must be included
- Full functionality and end to end testing needs to be done after major upgrades