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SRS Geometric Error in Source Target Guide (STG) Geometry Framework

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Abstract
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Abstract

Objectives:

This study abstracts the common features of SRS systems and proposes a framework to describe, define, measure, and model geometry and geometric errors.

Methods:

STG Geometry Framework describes, defines, measures, models, and corrects the geometric errors in SRS/SBRT. It has five points:
1. Geometry error is the vector difference of the tumor volume (Target) from the radiation field (Source);
2. Geometry errors are of two types in systematic and random:
a. The systematic error is due to an SRS machines' mechanical imperfection. Systematic error can be measured and modeled before the treatment starts;
b. The Random error is due to patient motion. Random error occurs during the process of patient setup and radiation delivery. It can be monitored (tracked) and corrected in real time;
3. An SRS machine is divided into three subsystems by the roles each plays in Source, Target, and Guide:
a. The Source Subsystem (SS) moves the radiation beams so that the beams focus to a point from multiple directions;
b. The Target Subsystem (TS) fixes a patient's head to a table using frame or mask and moves the target to the SS focal point;
c. The Guide Subsystem (GS) guides the movement of the table during the treatment setup using an absolute measuring "ruler" such as CBCT or stereo X-ray, and tracks the motion of the target during the treatment delivery using a relative measuring "ruler" such as non-radiation, optical or infrared based IGRT. The classic GS uses BRW stereotactic system, laser, and cross hair for the setup;
4. The focal point in SS is unique by nature and is chosen as the reference point (origin) for a 4D Cartesian space. This point is named Source Subsystem Isocenter (SSI) or Source Isocenter (SI). This point is commonly called Radiation Isocenter (RI);
5. The focal point is also the reference point of a 4D Cartesian system in the Treatment Planning System (TPS) with name in Treatment Isocenter (TI). The source-target relationship defined in TPS is materialized in machine via co-registration between the CT of the TPS and CBCT of the SRS machine. The TPS shall exactly model a mechanical-imperfect SRS machine so that What you see is what you get (WYSIWYG) is achieved

Results:

Use the STG Framework to illustrate three SRS systems in Gamma Knife (GK), Cyberknife (CK), and Linac SRS (XK).

1. Source Subsystem. GK Icon has 192 fixed beams with better than 0.1 mm precision. CK's SS is on a robot with single beam capable of 6 DoF movement in 0.2 mm resolution. XK's SS rotates 360 degrees with single beam but with MLC which make it possible to treat multiple targets with one rotation.
2. Target Subsystem. GK Icon has both frame and frameless fixation. Its table moves parallelly because the non-coplanar function is realized by multiple non-coplanar beams in SS. CK has mask only as the fixation. Its table moves only during setup. Although having frame historically, XK has mask only as the fixation now. Its table can move 180 degrees to realize the non-coplanar beam treatment.
3. Guide Subsystem. GK has a classic GS in BRW localization system when the frame fixation is used. For mask, a CBCT is used to setup in moving the target to the focal point of the SS. A High-Definition Motion Management (HDMM), which is non-radiation, tracks the target in real time with resolution of 0.02 mm. CK can re-stereo Xray every 5 sec to check the motion and correct, if necessary, by moving the SS's robot. XK's GK has multiple options in IGRT. Some are radiation based such as ExacTrac and other are non-radiation

such as VisionRT and C-Rad.
4. The focal point or isocenter has to be identified and registered and understood by all subsystems. It is where TS meets TS under GS.

The total geometric error is the combination of the systematic error and random error. The systematic error of SRS machines is within 1 mm. The random error, however, could be 0~3 or more, depends on the patients. The motion management works in theory but 1) an unwanted large gtv-ptv margin has to be introduced and 2) the treatments are interrupted and lasted much longer than the planned, seriously affecting the schedule.

Conclusion(s):

This study outlines a geometry framework to describes, defines, measures, models, and corrects the sub-mm geometric error in SRS systems. Much work is to be done.