Purpose: To verify the geometric accuracy of the X-ray image-based dynamic tracking for a four-dimensional (4D) image-guided radiotherapy system with gimbals mechanism of MHI-TM2000 (VERO).
Methods: This study was performed employing a 3D moving phantom with a steel-ball target of 9.5-mm-diameter; a laser displacement gauge; orthogonal kV x-ray imaging subsystem, a gimbaled X-ray head, and a system controller of MHI-TM2000. The moving phantom was driven based on the programmed motion patterns (seven periodic [Motion range: 20-40 mm, Breathing cycle: 2-5 s] and 15 of 3D patient's respiratory patterns). Subsequently, the displacements of the target were measured in real time by the laser-displacement gauge and the orthogonal kV x-ray imaging subsystem. Meanwhile, the system predicted the future target position, and then the orthogonal gimbals were transferred to the corresponding orientation. The transferred and the current orientation of the gimbals were recorded. Predicted target positional errors (EP), mechanical errors (EM) of the gimbals, and total tracking system errors (ET) derived from EP and EM were computed.
Results: Root mean square of ET (RMSET) was up to 0.68 mm for the periodic patterns. As for the entire patient's respiratory patterns, average RMS of EP, EM, and ET were 1.28, 0.12, and 1.24 mm, respectively. The principal component score which was computed from the patient's respiratory motion under the conditions of free breathing decreased with large amplitude, long breathing cycle and high breathing stability. A strong positive correlation was observed between the ratio of the RMSET to the amplitude and the principal component score of the respiratory motion ($R2 = 0.76$).
Conclusions: This study showed that MHI-TM2000 has the capability for high tracking accuracy. The prediction error mainly caused the total tracking system error while the mechanical error was negligible. In addition, tracking error can be predicted from the principal component analyses.

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