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Control devices and steering strategies in pathway surgery

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ABSTRACT

For pathway surgery, that is, minimally invasive procedures carried out transluminally or through instrument-created pathways, handheld maneuverable instruments are being developed. As the accompanying control interfaces of such instruments have not been optimized for intuitive manipulation, we investigated the effect of control mode (1DoF or 2DoF), and control device (joystick or handgrip) on human performance in a navigation task. The experiments were conducted using the Endo-PaC (Endoscopic-Path Controller), a simulator that emulates the shaft and handle of a maneuverable instrument, combined with custom-developed software animating pathway surgical scenarios. Participants were asked to guide a virtual instrument without collisions toward a target located at the end of a virtual curved tunnel. The performance was assessed in terms of task completion time, path length traveled by the virtual instrument, motion smoothness, collision metrics, subjective workload, and personal preference. The results indicate that 2DoF control leads to faster task completion and fewer collisions with the tunnel wall combined with a strong subjective preference compared with 1DoF control. Handgrip control appeared to be more intuitive to master than joystick control. However, the participants experienced greater physical demand and had longer path lengths with handgrip than joystick control.

1. Introduction

During the last decade, minimally invasive procedures are regularly carried out through natural openings in the human body with an endoscope after transluminal or instrument-created pathways (e.g., endo-nasal skull base surgery [1]). In these types of procedures, called pathway surgery throughout this article, instrument manipulation is constrained both by the incision point and by the curvature of the three-dimensional (3D) path (Fig. 1A and B).

To facilitate maneuvering through curved paths in the human anatomy, instruments with one or more steerable segments (called henceforth steerable and maneuverable instruments, respectively) are being developed [2–9] (Fig. 1C and D). Handheld maneuverable instruments for pathway surgery are still in their infancy, the accompanying control interfaces have generally not been optimized for dexterous steering [10]. In a review of control interfaces for steerable instruments, Fan *et al.* [10] argued that, among all existing methods of controlling steerable instruments, integrated single segment (ISS) maneuvering (Fig. 2A) is an intuitive method to follow 3D trajectories in pathway surgery [8,9]. With ISS maneuvering, the steering motion of the first segment is automatically transmitted backward along the

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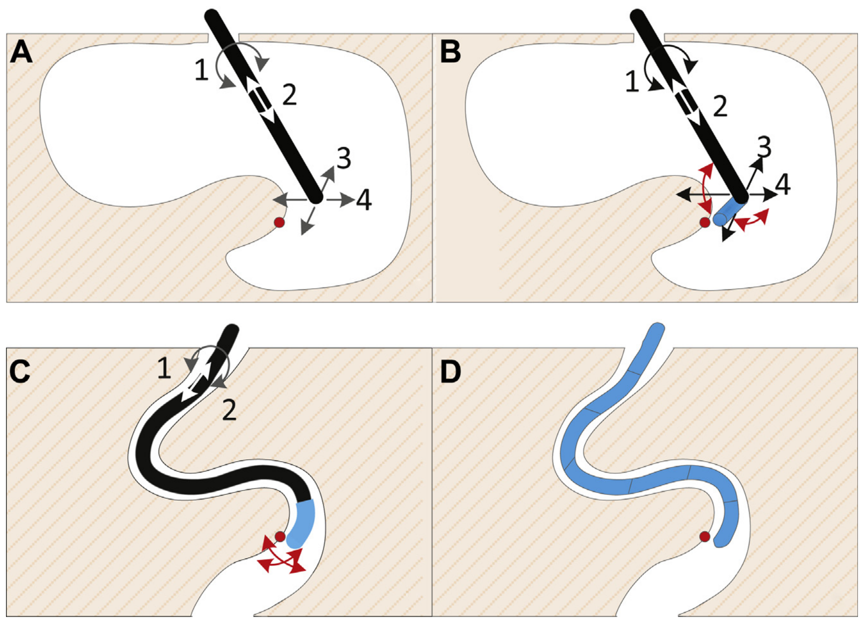

Fig. 1 – Illustration of instruments used in minimally invasive surgery: (A) rigid instrument, (B) flexible instrument, (C) flexible instrument with one steerable segment on the tip, (D) and instrument with multiple steerable segments along the shaft. (Color version of figure is available online.)

maneuverable shaft and copied by the preceding segments as the instrument moves forward. Requiring only one manual control device for the tip, it is expected that ISS maneuvering leads to a user experience similar to that of conventional steerable instruments in terms of eye-hand coordination and steering action.

1.1. *Control mode*

Fan *et al.* [10] made a subdivision of methods for ISS maneuvering based on the degrees of freedom of that tip (Fig. 2B–D). 3DoF control is mechanically complex [11–13], whereas 1DoF control and 2DoF control are simpler and commonly implemented in handheld steerable instruments [3,6,7,14–18]. 1DoF control has been applied in a variety of steerable catheters [15–18]. By deflecting the catheter tip and by rotating the catheter shaft in a circumferential plane, 1DoF control facilitates maneuvering through vascular structures and accessing side arteries is achieved [19,20]. 2DoF control has been incorporated in a number of flexible endoscopes, namely bi-directional gastroscopes and colonoscopies [21,22], in which the tip can be steered in two orthogonal directions.

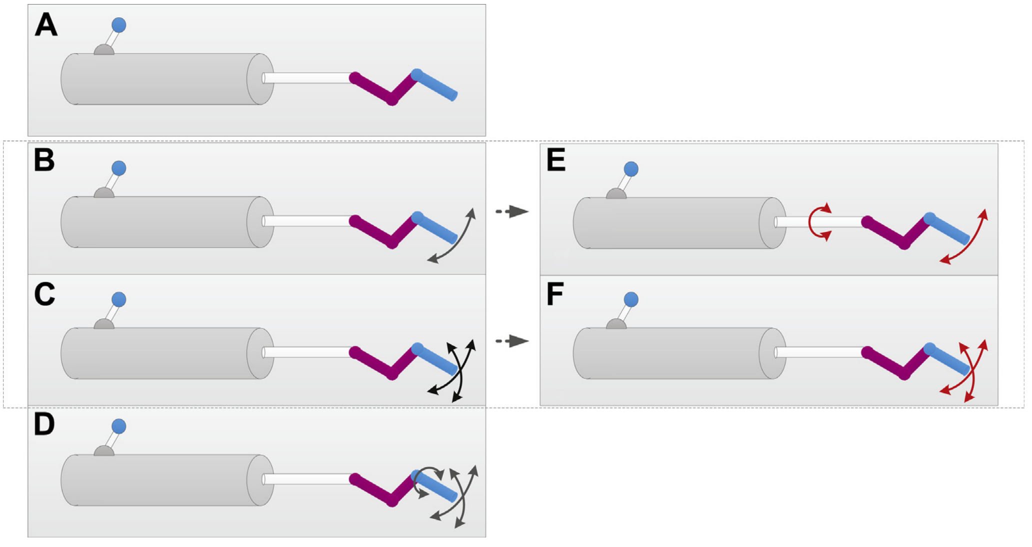

Fig. 2 – Sketch of ISS control and illustrations of DR (Deflection-Rotation) control and DD (Double-Deflection) control (adapted from [10]). (A) ISS control, (B) 1DoF ISS control, (C) 2DoF ISS control, (D) 3DoF ISS control, (E) DR control, (F) and DD control. (Color version of figure is available online.)