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Technical Note

A quality assurance device for measuring afterloader performance and transit dose for nasobiliary high-dose-rate brachytherapy

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ABSTRACT

PURPOSE: Nasobiliary high-dose-rate (HDR) brachytherapy has emerged as an effective tool to boost the radiation dose for patients with unresectable perihilar cholangiocarcinoma. This work describes a quality assurance (QA) tool for measuring the HDR afterloader's performance, including the transit dose, when the source wire travels through a tortuous nasobiliary catheter path.

METHODS AND MATERIALS: The nasobiliary QA device was designed to mimic the anatomical path of a nasobiliary catheter, including the nasal, stomach, duodenum, and bile duct loops. Two of these loops, the duodenum and bile duct loops, have adjustable radii of curvature, resulting in the ability to maximize stress on the source wire in transit. The device was used to measure the performance over time for the HDR afterloader and the differences between intraluminal catheter lots. An upper limit on the transit dose was also measured using radiochromic film and compared with a simple theoretical model.

RESULTS: The QA device was capable of detecting performance variations among nasobiliary catheter lots and following radioactive source replacement. The transit dose from a nasobiliary treatment increased by up to one order of magnitude when the source wire encountered higher than normal friction. Three distinct travel speeds of the source wire were observed: 5.2, 17.4, and 54.7 cm/s. The maximum transit dose was 0.3 Gy at a radial distance of 5 mm from a 40.3 kU ^{192}Ir source.

CONCLUSIONS: The source wire encounters substantially greater friction when it navigates through the nasobiliary brachytherapy catheter. A QA tool that mimics the nasal, stomach, duodenum, and bile duct loops may be used to evaluate transit dose and the afterloader's performance over time.

Keywords: Bile duct; High-dose-rate; Nasobiliary; ERCP; Intraluminal brachytherapy

Introduction

Nasobiliary high-dose-rate (HDR) brachytherapy has emerged as an effective tool to boost the radiation dose for patients with unresectable perihilar cholangiocarcinoma. HDR provides superior dose shaping and shorter treatment times than low-dose-rate brachytherapy or external beam radiotherapy, factors which may be associated with reduced duodenal/gastric toxicity (1). Five-year survival rates of approximately 50% are achievable with chemoradiotherapy and liver transplantation (2−4).

The nasobiliary catheter path is extensive and curved, and the HDR afterloader may have difficulty extending the radioactive source wire into the treatment site. The HDR afterloader performance may also change when the radioactive source is replaced or the unit is serviced. Our clinic developed a nasobiliary quality assurance (QA) device for measuring the afterloader unit's ability to extend the source wire under typical treatment conditions. The purpose of developing this device was two-fold. First, it allows us to quantify the ability of the nasobiliary catheter to traverse a high-friction path, so that we can elucidate and control, when possible, the factors that affect the afterloader performance as well as ensure that the more robust of our two afterloaders is used for HDR treatments. Second, it permits estimation of the transit dose, which is higher when delivered under high-friction conditions.

The QA device was designed with four curved regions that mimic the anatomical path of a nasobiliary catheter,

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representing the nasal, stomach, duodenum, and bile duct catheter loops. Two of these loops, the duodenum and bile duct loops, were designed to have variable radii of curvature, resulting in the ability to tune the stress on the source wire in transit. The nasobiliary QA device was used to measure performance variations among nasobiliary catheter lots and to monitor the afterloader unit's performance over time. Furthermore, the device was used to estimate the source wire transit doses that occur during nasobiliary brachytherapy treatments.

Methods and materials

Afterloader performance

The extension of a radioactive source wire through a nasobiliary catheter is analogous to the challenge encountered by electrical engineers who must guide electrical wires through conduit systems without damaging the wires. Cable pull forces are known to be linearly dependent on the length of the cable and nonlinearly dependent on the coefficient of friction between the cable and conduit sidewall, the diameter of the cable relative to the diameter of the conduit (conduit fill ratio), and the conduit radius of curvature (5). Similarly, the performance of the HDR afterloader is expected to be a function of the coefficient of friction between the source wire and nasobiliary catheter, the internal diameter of the catheter, the diameter of the source wire, and the rigidity of the catheter wall.

To test how nasobiliary catheter curvature affects the afterloader unit's performance, we designed a quasianatomical QA device (DOE #50860, Mayo Clinic, Rochester, NY) that mimics the extensive and curved nasobiliary path. Figure 1 illustrates the device design, which features the nasal (radius of curvature = 6.5 cm), stomach (radius of curvature = 5.5 cm), duodenum (5 possible paths, semimajor radius = 4.3–5.8 cm and semiminor radius = 2.8–4.3 cm), and bile duct (six possible paths, radius of curvature = 1.25–2.5 cm) loops. The dimensions for the loops were estimated using the treatment images from 20 patients. This design was chosen instead of a more traditional impact-based force gauge because it more closely probes the variables that might influence an HDR bile duct treatment. Engineering drawings for the QA device are available from the authors on request.

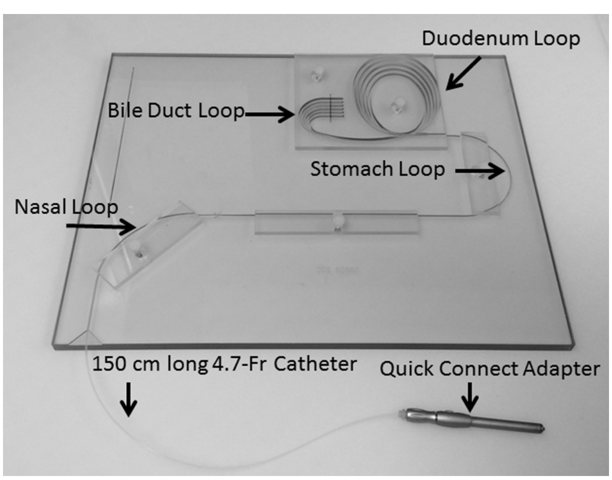

Fig. 1. Nasobiliary QA device. The QA device mimics the extensive and curved nasobiliary path. A 4.7-Fr catheter is placed into the device's grooved path. The curvature of the catheter path may be varied using 30 different settings. QA = quality assurance.

The device had a grooved path that accommodates a 4.7-Fr catheter. The curvature of the catheter path was varied using 30 different settings, including six major settings at the bile duct region and five minor settings at the duodenum region. A QA scoring metric was devised to correlate with the most highly curved path that the afterloader can traverse. The QA score, summarized in Table 1, is determined foremost by the radius of curvature for the bile duct region and secondarily by the semimajor and semiminor radii for the duodenum region. For example, the path with the highest QA score follows the smallest radii of curvature in the bile duct and duodenum regions and is identified with a score of 30. The second most difficult

Table 1
QA scoring system

QA score	Bile duct loop radius of curvature (cm)	Duodenum loop semiminor radius (cm)	Duodenum loop semimajor radius (cm)
30	1.25	2.80	4.30
29		3.18	4.68
28		3.55	5.05
27		3.93	5.43
26		4.30	5.80
25	1.50	2.80	4.30
24		3.18	4.68
23		3.55	5.05
22		3.93	5.43
21		4.30	5.80
20	1.75	2.80	4.30
19		3.18	4.68
18		3.55	5.05
17		3.93	5.43
16		4.30	5.80
15	2.00	2.80	4.30
14		3.18	4.68
13		3.55	5.05
12		3.93	5.43
11		4.30	5.80
10	2.25	2.80	4.30
9		3.18	4.68
8		3.55	5.05
7		3.93	5.43
6		4.30	5.80
5	2.50	2.80	4.30
4		3.18	4.68
3		3.55	5.05
2		3.93	5.43
1		4.30	5.80

QA = quality assurance.

The QA score is greater for pathways with smaller radii of curvature that are more difficult to traverse. The radii of curvature of the nasal and stomach loops are fixed (6.5 and 5.5 cm, respectively).