



A micro-costing analysis of outpatient flexible cystoscopy: implications for adoption of single-use flexible cystoscopes

门诊柔性膀胱镜检查的微观成本分析：对采用一次性柔性膀胱镜的影响

Zhuo T. Su¹ · Mitchell M. Huang¹ · Brian R. Matlaga¹ · Susan Hutfess^{2,3,4} · Kevin Koo^{1,5}

Received: 31 January 2021 / Accepted: 3 May 2021

© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract

Purpose To evaluate the total cost of outpatient flexible cystoscopy associated with reusable device purchase, maintenance, and reprocessing, and to assess potential cost benefits of single-use flexible cystoscopes.

目的

评估与可重复使用设备购买、维护和再处理相关的门诊柔性膀胱镜检查的总成本，并评估一次性柔性膀胱镜的潜在成本效益。

Methods Cost data regarding the purchasing, maintaining, and reprocessing of reusable flexible cystoscopes were collected using a micro-costing approach at a high-volume outpatient urology clinic. We estimated the costs to facilities with a range of annual procedure volumes (1000–3000) performed with a fleet of cystoscopes ranging from 10 to 25. We also compared the total cost per double-J ureteral stent removal procedure performed using single-use flexible cystoscopes versus reusable devices.

方法

在一家大批量门诊泌尿外科诊所使用微成本计算方法收集了有关可重复使用的柔性膀胱镜的购买、维护和再处理的成本数据。我们估计了使用 10 到 25 台膀胱镜进行的一系列年度手术量（1000–3000 次）的设施的成本。我们还比较了每次使用一次性柔性输尿管支架移除手术的总成本膀胱镜与可重复使用的设备。

Results The cost associated with reusable flexible cystoscopes ranged from \$105 to \$224 per procedure depending on the annual procedure volume and cystoscopes available. As a practice became more efficient by increasing the ratio of procedures performed to cystoscopes in the fleet, the proportion of the total cost due to cystoscope reprocessing increased from 22 to 46%. For ureteral stent removal procedures, the total cost per procedure using reusable cystoscopes (range \$165–\$1469) was higher than that using single-use devices (\$244–\$420), unless the annual procedure volume was sufficiently high relative to the number of reusable cystoscopes in the fleet (≥ 350 for a practice with ten reusable cystoscopes, ≥ 700 for one with 20 devices).

结果

与可重复使用的柔性膀胱镜相关的费用从每次手术 105 美元到 224 美元不等，具体取决于每年的手术量和可用的膀胱镜。随着通过增加机队中的膀胱镜手术比例来提高实践效率，膀胱镜再处理占总成本的比例从 22% 增加到 46%。对于输尿管支架移除手术，使用可重复使用的膀胱镜每次手术的总成本（165–1469 美元）高于使用一次性设备（244–420 美元），除非每年的手术量相对于可重复使用的膀胱镜的数量足够高（对于使用 10 个可重复使用的膀胱镜的实践， ≥ 350 ，对于使用 20 个设备的实践， ≥ 700 ）。

Conclusion The cost of reprocessing reusable cystoscopes represents a large fraction of the total cost per procedure, especially for high-volume facilities. It may be economical to adopt single-use cystoscopes specifically for stent removal procedures, especially for lower-volume facilities.

结论

再处理可重复使用的膀胱镜的成本占每次手术总成本的很大一部分，特别是对于大容量设施。采用专门用于支架移除程序的一次性膀胱镜可能是经济的，特别是对于容量较小的设施。

Keywords Reusable flexible cystoscopes · Cost · Cystoscope reprocessing · Single-use flexible cystoscopes · Micro-costing

Introduction

✉ Zhuo T. Su
zsu3@jhmi.edu

- ¹ The James Buchanan Brady Urological Institute, Johns Hopkins University School of Medicine, 600 N. Wolfe St, Baltimore, MD 21287, USA
- ² Department of Medicine, Division of Gastroenterology and Hepatology, Johns Hopkins University School of Medicine, Baltimore, MD, USA
- ³ Gastrointestinal Epidemiology Research Center, Johns Hopkins University, Baltimore, MD, USA
- ⁴ Department of Epidemiology, Johns Hopkins University Bloomberg School of Public Health, Baltimore, MD, USA
- ⁵ Department of Urology, Mayo Clinic, Rochester, MN, USA

Flexible cystoscopy is one of the most common urologic procedures performed in the office setting to diagnose and treat conditions in the lower urinary tract. Reprocessing reusable flexible cystoscopes after each procedure is essential for assessing instrument integrity [1] and reducing contamination-related infections [2–6]. The reprocessing of reusable cystoscopes is a multistep process that requires time and expense: (1) pre-cleaning, (2) leak-testing, manual cleaning, and visual inspection, (3) high-level disinfection, (4) rinsing, and (5) drying and storage. Reprocessing can therefore be a limiting factor in a urology practice where multiple providers need to perform a high number of procedures concurrently.

柔性膀胱镜检查是在临床环境下进行诊断和治疗的最常见的治疗下尿路疾病的泌尿外科手术之一。在每次手术后对可重复使用的柔性膀胱镜进行再处理对于评估器械完整性[1]和减少污染相关感染[2-6]至关重要。可重复使用膀胱镜的再处理是一个需要时间和费用的多步骤过程：（1）预清洗，（2）泄漏检测，手动清洗和目视检查，（3）高级消毒，（4）冲洗，以及（5）干燥和储存。因此，在多个提供者需要同时执行大量程序的泌尿外科实践中，再处理可能是一个限制因素。

To overcome this limitation, new technologies have been introduced, including disposable sheaths to shorten

the reprocessing time [7, 8] and more recently, single-use digital flexible cystoscopes which have been approved for double-J ureteral stent removal [9, 10]. Potential benefits of these technologies in clinical practice include ease of clinical integration and cost savings in comparison to reusable flexible cystoscopes. However, there are currently limited data on the cost associated with reprocessing reusable cystoscopes to inform practice-level decisions regarding adoption of single-use flexible cystoscopes.

为了克服这一局限性, 引入了新技术, 包括一次性通道鞘以缩短再处理时间[7,8], 以及最近批准用于双J输尿管支架拆除的一次性数字柔性膀胱镜[9,10]。与可重复使用的柔性膀胱镜相比, 这些技术在临床实践中的潜在好处包括易于临床集成和节省成本。然而, 目前关于后处理可重复使用膀胱镜相关成本的数据有限, 无法为采用一次性柔性膀胱镜的实践决策提供信息。

Micro-costing is an effective method that allows precise estimation of the likely costs of health care interventions [11]. This method has been utilized in a recent analysis to assess the cost of purchasing, reprocessing, and maintaining reusable colonoscopes, in a similar context of evaluating the economic benefit of adopting disposable colonoscopes [12]. To investigate potential cost benefits of single-use flexible cystoscopes, we employed micro-costing to evaluate the total potential costs and cost-savings associated with the purchase, maintenance, and reprocessing of reusable flexible cystoscopes in urology practices.

微观成本计算是一种有效的方法, 可以精确估计卫生保健干预措施的可能成本[11]。在最近的一次分析中, 该方法被用于评估购买、再加工和维护可重复使用结肠镜的成本, 在评估采用一次性结肠镜的经济效益的类似背景下[12]。为了研究一次性柔性膀胱镜的潜在成本效益, 我们采用微观成本法评估在泌尿外科实践中与购买、维护和重新处理可重复使用柔性膀胱镜显微镜相关的总潜在成本和成本节约。

。

Methods

All cost data regarding the purchasing, maintaining, and reprocessing of reusable flexible cystoscopes were obtained at a high-volume outpatient urology clinic (Johns Hopkins Outpatient Center, Baltimore, Maryland, United States). Where cost estimates for specific items were not available, we utilized values reported from the existing academic and commercial literature. All cost data were collected in United States dollars using a micro-costing approach.

与可重复使用的柔性膀胱镜的购买、维护和再加工相关的所有成本数据都是从一家大容量门诊泌尿科诊所获得的(美国马里兰州巴尔的摩市约翰·霍普金斯门诊中心

州)。如果无法获得特定项目的成本估算, 我们使用现有学术和商业文献中报告的价值。所有成本数据都是使用微观成本计算方法以美元收集的。

Capital costs

Purchase costs of reusable flexible cystoscopes and accessories, camera platforms and associated hardware, and equipment used for reprocessing cystoscopes are detailed in Supplemental Tables 1 and 2. We assumed three sets of camera platforms at a urology practice. Capital costs of reusable cystoscopes and accessory devices were amortized over 5 years, and capital costs of camera platforms and associated hardware were amortized over 8 years. For cystoscope reprocessing, we assumed two automated endoscopic processors (AERs), typically used for high-level disinfection of cystoscopes during reprocessing, available at a urology practice regardless of annual procedure volume. The AERs and drying cabinets were amortized over 8 years. Capital costs were discounted at 3.5% per year to calculate the present value of capital expenditures.

可重复使用的柔性膀胱镜和附件、相机平台和相关硬件以及用于后处理膀胱镜的设备的采购成本详见补充表1和2。我们假设在泌尿科诊所所有三套相机平台。可重复使用膀胱镜和辅助设备的资本成本在5年内摊销, 相机平台和相关硬件的资本成本则在8年内摊销。对于膀胱镜后处理, 我们假设有两个自动内镜后处理器(AER), 通常用于后处理期间膀胱镜的高级消毒, 无论年度手术量如何, 均可在泌尿科诊所使用。AER和干燥柜在8年内摊销。资本成本以每年3.5%的贴现率计算资本支出的预先发送值。

Costs of disposable supplies and equipment repairs

We itemized the costs of common disposable supplies used during an outpatient flexible cystoscopy procedure for diagnosing urinary tract pathology (Supplemental Table 3). The average cost of repairs per AER was \$7831.25 per year based on manufacturer estimates [13]. We assumed that each reusable cystoscope was repaired once every 495.4 procedures for an average repair cost of \$5.41 per procedure, according to estimates from a prospective study of cystoscope durability [1].

我们逐项列出了门诊柔性膀胱镜检查过程中用于诊断泌尿系疾病的常用一次性用品的成本（补充表3）。根据制造商的估计，每个AER的平均维修成本为每年7831.25美元[13]。根据膀胱镜耐久性前瞻性研究的估计，我们假设每个可重复使用的膀胱镜每495.4次手术修复一次，平均修复成本为5.41美元。

Costs of reprocessing reusable flexible cystoscopes

The cost of supplies used for reprocessing reusable cystoscopes (Supplemental Table 4) was estimated in two steps. First, in a recent study performed at our institution, the supplies used for reprocessing 25 reusable colonoscopes over a 3-day period were tracked using the micro-costing approach [12]. Then, we verified item by item that reprocessing of reusable flexible cystoscopes requires use of the same supplies and equipment at our institution. Average personnel time spent on each step of manual reprocessing of one cystoscope was derived based on estimates from a recent clinical trial [8]. These estimates were also verified to be consistent with the average amount of time spent on manual reprocessing of cystoscopes at our institution.

用于后处理可重复使用膀胱镜的用品成本（补充表4）分两步估算。首先，在我们机构最近进行的一项研究中，使用微成本法跟踪了三天内用于再处理25个可重复使用结肠镜的供应[12]。然后，我们逐项验证了再加工可重复使用的柔性膀胱镜需要使用我们机构的相同用品和设备。根据最近一项临床试验的估计，得出人工重新处理膀胱镜每个步骤所需的平均人员时间[8]。这些估计值也与我们机构人工重新处理膀胱镜所花费的平均时间相一致。

Infection-related treatment costs

Regarding the costs of treating possible infections after outpatient flexible cystoscopy (Supplemental Table 5), we assumed that that 6.6% of patients present for a follow-up office visit [14], 1.9% have a febrile urinary tract infection requiring oral antibiotics [4], and none develop bacterial sepsis requiring hospitalization [4] based on incidence rates observed in cohort studies.

关于门诊患者柔性膀胱镜检查后可能感染的治疗费用（补充表5），根据队列研究中观察到的发病率，我们假设6.6%的患者需要进行随访[14]，1.9%的患者患有需要口服抗生素的发热性尿路感染[4]，无一患者发生需要住院治疗的细菌败血症[4]。

Primary analyses

We used the cost estimates mentioned above to project the total cost per use of reusable flexible cystoscopes to a urology practice with a range of annual procedure volumes (1000–3000) performed with a fleet of cystoscopes ranging from 10 to 25 cystoscopes. The tested range for annual procedure volumes was based on typical annual volumes of outpatient diagnostic flexible cystoscopy procedures performed at our center.

我们使用上述成本估算，将每次使用可重复使用的柔性膀胱镜的总成本预测到泌尿外科实践中，每年使用10到25个膀胱镜进行一英尺的膀胱镜进行手术量（1000到3000）。年度手术量的测试范围基于我们中心进行的门诊诊断性柔性膀胱镜检查的典型年度手术量。

Secondary analysis

We performed a secondary analysis to compare the costs of performing double-J ureteral stent removal procedures in the

office setting using reusable flexible cystoscopes versus single-use flexible cystoscopes. For this analysis, we assumed a purchase cost of \$200 per single-use flexible cystoscope, and a unit purchase cost of \$788.49 for reusable flexible grasping forceps, based on cost estimates at our institution. We assumed three sets of grasping forceps available at a practice. The costs of grasping forceps were amortized over 1 year. In calculating the total cost per procedure associated with single-use flexible cystoscopes, we included the same purchase costs of camera platforms and associated hardware (i.e., display monitor, camera platform, equipment cart, printer and documentation system) and disposable supplies used per procedure, and we excluded the costs of reusable cystoscope repairs and reprocessing. In the base-case analysis, we excluded the cost of infection-related treatment for single-use devices. In a sensitivity analysis, we included the infection-related treatment cost for single-use devices by assuming the same rates of infection after reusable devices. We compared the per-procedure cost to a urology practice performing a range of stent removal procedures annually (100–900) using a fleet of 10–25 flexible reusable cystoscopes versus single-use flexible cystoscopes exclusively. 我们进行了二次分析，比较了在临床环境使用可重复使用的柔性膀胱镜和单用柔性膀胱显微镜进行双J输尿管支架拆除手术的成本。为了进行此分析，根据我们机构的成本估算，我们假设一次性柔性膀胱镜的采购成本为200美元，可重复使用的柔性抓钳的单位采购成本为788.49美元。我们假设一家诊所所有三套可用的抓取钳。抓取钳的成本在一年内摊销。在计算一次性柔性膀胱镜相关的每个手术的总成本时，我们包括了相同的相机平台和相关硬件（即显示器、相机平台、设备推车、打印机和文档系统）的采购成本以及每个手术使用的一次性用品，并且我们排除了可重复使用膀胱镜的维修和再处理成本。在基本案例分析中，我们排除了一次性使用器械的感染相关治疗费用。在敏感性分析中，我们通过假设重复使用设备后感染率相同，将一次性使用设备的感染相关治疗成本包括在内。我们将每次手术的成本与泌尿外科每年（100–900）使用10–25英尺可重复使用的柔性膀胱镜进行一系列支架拆除手术的成本进行了比较，而不是仅使用一次性柔性膀胱显微镜。

Results

Primary analysis for outpatient diagnostic cystoscopy procedures

The per-procedure cost associated with reusable flexible cystoscopes was highly dependent on the annual procedure volume and the number of cystoscopes available at a urology practice (Supplemental Fig. 1). As the annual procedure volume varied between 1000 and 3000 and the available cystoscopes varied from 10 to 25, the cost per procedure ranged from \$105.47 to \$224.36. Divided into individual cost categories, the capital cost per procedure ranged widely from \$21.94 to \$135.61 depending on the annual procedure volume and the number of cystoscopes in the fleet (Table 1). The average cost of equipment repairs per procedure performed varied from \$8.02 to \$13.24 depending on the annual procedure volume. The estimated per-procedure cost for the other cost categories was independent of the annual procedure volume and number of cystoscopes available. The cost of disposable supplies used per procedure was \$21.78. For the cost of reprocessing reusable flexible cystoscopes, the cost of supplies used in reprocessing of one cystoscope was \$25.23 and the personnel cost for time spent on manual cleaning and disinfecting one cystoscope was \$23.64, adding up to an overall reprocessing cost of \$48.87 per procedure. Personnel cost accounted for 48% of the reprocessing cost. In addition, the infection-related treatment cost was on average \$4.85 per procedure.

与可重复使用柔性膀胱镜相关的每次手术成本高度依赖于每年手术量和泌尿科诊所可用膀胱镜的数量（补充图1）。由于每年的手术量在1000到3000之间，可用的膀胱镜数量在10到25之间，因此每个手术的成本在105.47美元到224.36美元之间。根据每年的手术数量和膀胱镜的数量，每个手术的资本成本从21.94美元到135.61美元不等（表1）。根据年度程序量，每个程序的平均设备维修成本从8.02美元到13.24美元不等。其他成本类别的预计每项手术成本独立于年度手术量和可用膀胱镜数量。每个手术使用的一次性用品成本为21.78美元。对于可重复使用的柔性膀胱镜的再加工成本，一个膀胱镜再加工使用的用品成本为25.23美元，人工清洁和消毒一个膀胱显微镜所花费的时间的人员成本为23.64美元，加起来每个手术的总再加工成本为48.87美元。人员成本占后处理成本的48%。此外，与感染相关的治疗费用平均为每项手术4.85美元。

Table 1 Estimation of the per-procedure costs of reusable flexible cystoscopes by varying annual number of procedures and number of cystoscopes available at a urology practice

表1 通过改变泌尿科每年可用的手术次数和膀胱镜数量，估算可重复使用柔性膀胱镜的每次手术成本

| Summary of costs 总花费 | 1000 procedures 1000次程序 | 2000 procedures 2000次程序 | 3000 procedures 3000次程序 | Costs that will remain with single-use flexible cysto- Scope 一次性柔性膀胱镜的成本 |
|--|----------------------------|----------------------------|----------------------------|--|
| Capital cost 10 cystoscopes 资本成本 10个膀胱镜 | \$65.83 | \$32.92 | \$21.94 | Yes; purchase of single-use flexible cystoscope per procedure, camera platform, and associated hardware 是：按程序购买一次性柔性膀胱镜、相机平台和相关硬件 |
| 15 cystoscopes 15个膀胱镜 | \$89.09 | \$44.55 | \$29.70 | |
| 20 cystoscopes 20个膀胱镜 | \$112.35 | \$56.18 | \$37.45 | |
| 25 cystoscopes 25个膀胱镜 | \$135.61 | \$67.81 | \$45.20 | |
| Disposable supply cost 一次性设备花费 | \$21.78 | | | |
| Repair cost 维修费用 | \$13.24 | \$9.33 | \$8.02 | No |
| Reprocessing cost: supplies 再加工成本：耗材 | \$25.23 | | | No |
| Reprocessing cost: personnel 再加工成本：人工 | \$23.64 | | | No |
| Infection-related treatment cost 感染相关治疗费用 | \$4.85 | | | Not for infections caused by cystoscope cross-contamination 不适用于膀胱镜交叉感染引起的感染 |
| Total cost 总花费 | | | | |
| 10 cystoscopes 10个膀胱镜 | \$154.58 | \$117.74 | \$105.47 | |
| 15 cystoscopes 15个膀胱镜 | \$177.84 | \$129.37 | \$113.22 | |
| 20 cystoscopes 20个膀胱镜 | \$201.10 | \$141.01 | \$120.97 | |
| 25 cystoscopes 25个膀胱镜 | \$224.36 | \$152.64 | \$128.73 | |

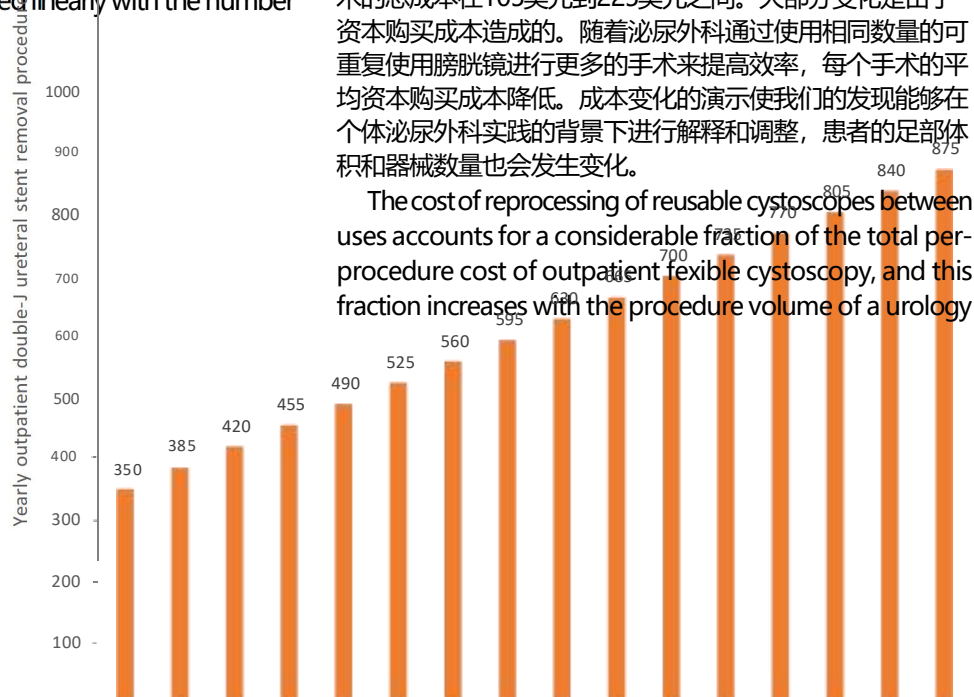
As a practice became more efficient by increasing the ratio of annual procedure volume to cystoscopes in the feet (i.e., moving from the left lower corner to the right upper corner of Supplemental Fig. 1), the proportion of the total per-procedure cost due to cystoscope reprocessing increased from 22 to 46% (Supplemental Fig. 2a), while that due to capital purchase decreased from 60 to 21% (Supplemental Fig. 2b).

随着一种做法通过增加每年手术量与膀胱镜检查的比率而变得更加有效（即，从补充图1的左下角移到右上角），膀胱镜再处理导致的每次手术总成本的比例从22%增加到46%（补充图2a），而由于资本购买而减少的比例从60%降至21%（补充图2b）。

Secondary analysis for double-J ureteral stent removal procedures 输尿管双J支架取出术的二次分析

As the number of stent removal procedures performed annually at a practice increased from 100 to 900, the total cost per procedure associated with using single-use reusable cystoscopes decreased from \$420.13 to \$243.82. Supplemental Fig. 3 compares the per-procedure costs for single-use versus reusable cystoscopes. Unless the annual procedure volume was sufficiently high, the per-procedure cost associated with single-use cystoscopes would be lower than that with reusable cystoscopes. For example, if a practice performed fewer than 350 procedures per year using a fleet of ten reusable cystoscopes, the practice would incur a lower total cost per procedure if the practice performed the same number of procedures annually using entirely single-use cystoscopes. The more reusable cystoscopes already available at a urology practice, the higher the break-even annual procedure volume in terms of per-procedure cost for switching to exclusively single-use cystoscopes (Fig. 1). The break-even procedure volume increased linearly with the number

Fig. 1 The number of outpatient double-J ureteral stent removal procedures a urology practice needs to perform annually given the number of reusable flexible cystoscopes already available at the practice in order for the total cost per procedure performed using reusable cystoscopes to be lower than the total cost per procedure performed using single-use devices



of reusable devices owned by a practice. In the sensitivity analysis where we applied the infection-related treatment costs associated with reusable devices to single-use devices, the break-even procedure volumes did not change considerably from the base-case analysis where such costs were excluded for single-use devices (Supplemental Fig. 4).

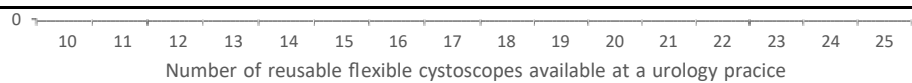
随着每年在一家诊所进行的支架拆除手术次数从100次增

Discussion

Our study illustrates that the total per-procedure cost of outpatient flexible cystoscopy, including purchase, maintenance, reprocessing, and infection-related treatment, varies considerably depending on the annual procedure volume and number of reusable cystoscopes available at a urology practice. Over the range of annual procedure volumes and available cystoscopes tested in our analysis, the total cost per procedure ranges between \$105 and \$225. Most of the variation is due to capital purchase cost. As a urology practice gains efficiency by performing a greater volume of procedures using the same number of reusable cystoscopes, the average capital purchase cost per procedure performed decreases. The demonstration of cost variation allows our findings to be interpreted in and adapted to the context of individual urology practices with varying patient volumes and device quantities in their fleet.

我们的研究表明，门诊柔性膀胱镜检查（包括购买、维护、再处理和感染相关治疗）的每项手术总成本，根据泌尿科诊所每年的手术量和可重复使用膀胱镜的数量有很大差异。在我们分析中测试的年度手术量和可用膀胱镜范围内，每个手术的总成本在105美元到225美元之间。大部分变化是由于资本购买成本造成的。随着泌尿外科通过使用相同数量的可重复使用膀胱镜进行更多的手术来提高效率，每个手术的平均资本购买成本降低。成本变化的演示使我们的发现能够在个体泌尿外科实践的背景下进行解释和调整，患者的足部体积和器械数量也会发生变化。

The cost of reprocessing of reusable cystoscopes between uses accounts for a considerable fraction of the total per-procedure cost of outpatient flexible cystoscopy, and this fraction increases with the procedure volume of a urology



practice. In a practice performing 3000 outpatient diagnostic cystoscopy procedures annually, the cost of cystoscope reprocessing may account up to nearly half of the total cost per procedure. This result highlights that in order for a urology practice to achieve a high procedure volume, a considerable amount of time and expense needs to be spent on cleaning and disinfecting of devices after each use.

在门诊柔性膀胱镜每次操作的总成本中，在使用之间重新处理可重复使用膀胱镜的成本占相当大的一部分，并且这一部分随着泌尿外科手术量的增加而增加。在每年进行3000次门诊诊断性膀胱镜检查的实践中，膀胱镜后处理的成本可能占每次检查总成本的近一半。这一结果突出表明，为了使泌尿外科实践达到较高的程序量，每次使用后都需要花费大量的时间和费用来清洁和消毒设备。

For double-J ureteral stent removal procedures, on the basis of total cost per procedure performed, our analysis showed that adopting single-use flexible cystoscopes may be economical for a urology practice unless the practice performs a high volume of these procedures. This is because the unit purchase cost is much higher for a reusable cystoscope than a single-use device. The number of procedures performed thus needs to be sufficiently high in relation to the number of reusable cystoscopes already purchased by a practice for the average purchase cost of reusable devices per procedure to be lower than the purchase cost of a single-use cystoscope. Furthermore, reusable cystoscopes would incur additional costs due to device repairing and reprocessing. Therefore, for urology practices that do not perform a very high volume of stent removal procedures (i.e., < 350 procedures annually for a practice owning ten reusable cystoscopes, and < 700 procedures annually for a practice owning 20 devices), they may achieve cost savings by performing these procedures exclusively using single-use devices.

对于双J型输尿管支架取出术，基于每项手术的总成本，我们的分析表明，除非手术量很大，否则采用一次性柔性膀胱镜对于泌尿外科手术可能是经济的。这是因为可重复使用的膀胱镜的单位购买成本比一次性使用的设备高得多。因此，与机构已经购买的可重复使用膀胱镜数量相比，所执行的手术数量需要足够高，以便每个手术可重复使用设备的平均购买成本低于一次性膀胱镜的购买成本。此外，可重复使用的膀胱镜会因设备维修和再加工而产生额外费用。因此，对于不执行大量支架拆除程序的泌尿外科实践（即，拥有10个可重复使用膀胱镜的实践每年<350个程序，拥有20个设备的实践每年<700个程序），他们可以通过仅使用一次性设备执行这些程序来实现成本节约。

Our study adds to a currently limited base of literature on the economic comparisons between reusable and single-use flexible cystoscopes. To our knowledge, only two existing studies have compared the costs of performing stent removal procedures using single-use versus reusable flexible cystoscopes. An Italian study compared the average per-procedure cost of 127 stent removal procedures using single-use flexible cystoscopes in the office setting versus 170 stent removal procedures performed using three reusable flexible

cystoscopes in the operating room (OR). This study tracked the device purchase, repair, and reprocessing cost as well as OR occupancy cost and found that overall, single-use devices had a lower total cost per procedure [10]. In contrast to the Italian study, our analysis examined the cost of stent removal procedures in the office setting for both single-use and reusable cystoscopes. Additionally, we included the cost of infection-related treatment following procedures performed using reusable cystoscopes. The second study was a recently published analysis of nearly 900 stent removal procedures performed using reusable flexible cystoscopes, in which the estimated cost per procedure, including purchase, maintenance, and reprocessing, was \$161.85 [15]. This study further reported that if the procedure volume was low (< 704), the cost per stent removal procedure performed using single-use cystoscopes would be lower than that using reusable cystoscopes, a conclusion supported by our calculations. In comparison to this study, our study conducted a

more thorough cost comparison by additionally assessing the costs of capital equipment including the camera platforms and associated hardware, disposable supplies used during each procedure, and treatment of infections after procedures. Furthermore, in comparison to both of the existing studies, our study projected the cost comparisons to a wide range of annual procedure volumes and number of reusable devices in the feet, instead of a fixed procedure volume and a specific number of reusable devices available at the respective study institution.

我们的研究增加了目前关于可重复使用和一次性柔性膀胱镜之间经济比较的有限文献基础。据我们所知, 只有两项现有研究比较了一次性使用支架和可重复使用的柔性膀胱镜进行支架拆除的成本。一项意大利研究比较了在手术室 (OR) 使用三个可重复使用的柔性膀胱镜 (flexible cystoscope) 和在office环境下使用一次性柔性膀胱显微镜 (single-use flexible cystoscope) 进行的127次支架拆除术的平均每次成本。这项研究跟踪了设备购买、维修和再加工成本以及手术室占用成本, 发现总体而言, 一次性设备的每项操作总成本较低[10]。与意大利的研究相反, 我们的分析检查了一次性和可重复使用膀胱镜在office设置下支架拆除程序的成本。此外, 我们还包括了使用可重复使用膀胱镜进行手术后感染相关治疗的费用。第二项研究是最近发表的一份分析报告, 分析了近900个使用可重复使用柔性膀胱镜进行的支架拆除手术, 其中每个手术的估计成本, 包括采购、维护和再加工, 为161.85美元[15]。本研究进一步报告, 如果手术量较低 (<704), 使用一次性膀胱镜进行的每次支架拆除手术的成本将低于使用可重复使用的膀胱镜, 这一结论得到了我们计算的支持。与本研究相比, 我们的研究通过额外评估资本设备的成本, 包括相机平台和相关硬件、每次手术中使用的一次性用品以及手术后感染的治疗, 进行了更彻底的成本比较。此外, 与现有的两项研究相比, 我们的研究将成本比较预测为各种年度手术量和足部可重复使用器械的数量, 而不是各研究机构提供的固定手术量和特定数量的可重复使用设备。

Our study highlights that the economic decision to integrate single-use flexible cystoscopes needs to be individualized for any given urology practice based on the procedure volume of the practice and the amount of capital equipment already purchased by the practice. Currently, single-use flexible cystoscopes have only been approved for ureteral stent removal procedures and do not yet provide sufficient image quality to be used for diagnostic cystoscopy procedures. Therefore, reusable cystoscopes remain indispensable for any urology practice. For stent removal procedures specifically, our analysis results favor switching to single-use devices for a practice with a low volume of these procedures. This may be the case, for example, for a newly established practice, or a practice that does not yet own reprocessing equipment to allow for a large procedure volume. For an established practice regularly performing outpatient stent removals, the economic consideration needs to assess both the procedure volume and the number of reusable cystoscopes already purchased by the facility. If a practice in question has the equipment and efficiency to perform suf-

ficiently many procedures using relatively few reusable cystoscopes in the feet, it would likely be economical for the practice to continue with reusable devices. But if the practice had to purchase, utilize, and maintain a large fleet of reusable devices to sustain the procedure volume, switching to single-use devices may lead to cost savings by reducing the cost of cystoscope maintenance and reprocessing. Lastly, even for a highly efficient practice maintaining a large procedure volume, there may still be a role of single-use flexible cystoscopes, such as reserving these devices in stent removal procedures for patients at a higher risk of infections, including those with recurrent infections and those who are immunocompromised (e.g., kidney transplant). Further research is thus needed to evaluate the potential clinical benefit of single-use devices in these specific settings.

我们的研究强调, 集成一次性柔性膀胱镜的经济决策需要根据机构的手术量和机构已购买的资本设备数量, 针对任何特定泌尿外科机构进行个体化。目前, 一次性柔性膀胱镜仅被批准用于输尿管支架拆除术, 尚不能提供足够的图像质量用于诊断性膀胱镜检查。因此, 可重复使用的膀胱镜对于任何泌尿外科实践都是不可或缺的。具体来说, 对于支架拆除程序, 我们的分析结果支持在这些程序量较少的情况下, 切换到一次性设备。例如, 对于一个新建立的机构, 或一个尚未拥有后处理设备以允许较大程序量的机构, 可能会出现这种情况。对于定期进行门诊支架拆除的既定实践, 经济考虑需要评估手术量和设施已购买的可重复使用膀胱镜的数量。如果有问题的机构有足够的设备和效率, 能够使用足部相对较少的可重复使用的显像管执行足够多的程序, 那么继续使用可重复使用设备可能是经济的。但是, 如果该机构必须购买、使用和维护大量可重复使用的设备来维持手术量, 那么切换到一次性设备可能会降低膀胱镜维护和再处理的成本, 从而节省成本。最后, 即使对于保持大手术量的高效实践, 一次性柔性膀胱镜仍可能发挥作用, 例如为感染风险较高的患者 (包括复发感染患者和免疫调节 (如肾移植) 患者) 在支架拆除过程中保留这些设备。因此, 需要进一步研究, 以评估在这些特定环境中一次性使用设备的潜在临床效益。

Our study has several limitations. Our cost estimates are minimum estimates. We did not include costs related to initial personnel training, time spent on documentation of cystoscope repairs, and recurring training for compliance with reprocessing guidelines. The true cost is likely higher if overhead costs, additional reprocessing and equipment purchase costs are included, such as repeat reprocessing after a prolonged period of storage, cost of disposing single-use

flexible cystoscopes and single-use accessories, conducting internal audits, and utility bills. Additionally, our study did not account for the environmental impact of disposable single-use flexible cystoscopes, which was beyond the scope of the study but a relevant consideration in the widespread adoption of single-use devices [16]. The environmental impact per use of device is likely much higher for single-use cystoscopes than reusable cystoscopes, given the carbon footprint that goes into manufacturing each single-use device which gets disposed after one use. This difference in carbon footprint may be partially offset by energy cost associated with reprocessing reusable devices. Further, our results, derived mostly using cost estimates at a single institution, may not be generalizable to other practices and geographies due to regional variation in practice patterns. In particular, our assumptions derived from our institution, such as those regarding equipment lifespan, may not be applicable to centers and health care systems around the world. Nonetheless, the pattern of cost variation identified in our study, and in particular, the study implications suggesting the potential economic benefit of adopting single-use cystoscopes for many urology practices, is likely valid regardless of location. By incorporating variation in the size of cystoscope feet and reprocessing equipment, our findings should be relevant to urology practices of diverse sizes and procedural patterns.

我们的研究有几个局限性。我们的成本估算是最低估算。我们没有包括与初始人员培训、膀胱镜维修记录所花费的时间以及为遵守后处理指南而进行的定期培训相关的费用。如果包括间接费用、额外的再加工和设备采购费用，如长时间储存后的重复再加工、一次性柔性膀胱镜和一次性配件的处理费用、进行内部审计和水电费账单，实际成本可能会更高。此外，我们的研究没有考虑一次性一次性柔性膀胱镜对环境的影响，这超出了研究范围，但在广泛采用一次性设备方面是一个相关的考虑因素[16]。考虑到制造每次使用一次后处理的一次性设备所需的碳足迹，一次性膀胱镜的每次使用对环境的影响可能比可重复使用的膀胱镜高得多。碳足迹的这种差异可能在一定程度上被和再处理可重复使用设备相关的能源成本所抵消。此外，由于实践模式的区域差异，我们的结果（主要使用单个机构的成本估算得出）可能无法推广到其他实践和地理区域。特别是，我们从我们的机构中得出的假设，例如关于设备寿命的假设，可能不适用于世界各地的消费者和医疗保健系统。尽管如此，我们的研究中确定的成本变化模式，特别是表明在许多泌尿外科实践中采用一次性膀胱镜的潜在经济效益的研究意义，无论在哪里，都是有效的。通过合并膀胱镜脚大小和后处理设备的变化，我们的发现应该与不同大小和程序模式的泌尿外科实践相关。

Conclusion

While the cost of reusable flexible cystoscopes is highly dependent on the number of cystoscopes available and annual procedural volume at individual urology practices, the cost of reprocessing reusable cystoscopes after each use

represents a large proportion of the total per-procedure cost for high-volume practices. For ureteral stent removal procedures for which single-use flexible cystoscopes have been developed and approved, integrating single-use devices may yield cost savings for many urology practices, particularly those with lower procedural volume and those with sufficiently high procedural volume to require maintenance of a large fleet of reusable cystoscopes.

虽然可重复使用的柔性膀胱镜的成本高度依赖于可用膀胱镜的数量和个体泌尿科诊所的年度手术量，但每次使用后再处理可重复使用膀胱镜的费用占高容量诊所每次手术总成本的很大比例。对于一次性使用柔性膀胱镜已经开发和批准的输尿管支架拆除程序，集成一次性设备可能会为许多泌尿外科实践节省成本，特别是那些手术量较小和手术量足够大，需要维护大量可重复使用膀胱镜的患者。

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s00345-021-03724-3>.

Acknowledgements We would like to thank Patricia Young, Department of Urology, Johns Hopkins University, for her time and assistance with identifying cost estimates for this study.

Authors' contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by ZTS, MMH, SH, and KK. The first draft of the manuscript was written by ZTS, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding None.

Data availability Full data provided in the data tables.

Code availability Available upon request.

Declarations

Conflict of interest Dr. Brian R. Matlaga is a consultant for Boston Scientific. No other competing financial interests exist.

Ethics approval N/A (no human subjects involved in this study).

References

1. McGill JJ, Schaefer AJ, Gonzalez CM (2013) Durability of flexible cystoscopes in the outpatient setting. *Urology* 5:932–937
2. Clemens JQ, Dowling R, Foley F, Goldman HB, Gonzalez CM et al (2010) Joint AUA/SUNA white paper on reprocessing of flexible cystoscopes. *J Urol* 6:2241–2245
3. Almallah YZ, Rennie CD, Stone J, Lancashire MJR (2000) Urinary tract infection and patient satisfaction after flexible cystoscopy and urodynamic evaluation. *Urology* 1:37–39
4. Herr HW (2015) The risk of urinary tract infection after flexible cystoscopy in patients with bladder tumor who did not receive prophylactic antibiotics. *J Urol* 2:548–551
5. Wendelboe AM, Baumbach J, Blossom DB, Frank P, Srinivasan A et al (2008) Outbreak of cystoscopy related infections with *Pseudomonas aeruginosa* : New Mexico, 2007. *J Urol* 2:588–592
6. Sorbets E, Evrein M, Jumas-Bilak E, Masnou A, Lotthé A et al (2019) An outbreak of *Pseudomonas aeruginosa* urinary tract infections following outpatient flexible cystoscopy. *Am J Infect Control* 12:1510–1512
7. McCombie SP, Carmichael JP, Banerjee S, Wood SJ (2013) Urinary tract infection following flexible cystoscopy: a comparison between sterilised cystoscopes and disposable sterile sheaths. *J Clin Urol* 4:220–224
8. Zambon JP, Watkins TP, Hemal A, Evans RJ, Gutierrez-Aceves J et al (2019) Evaluation of clinical use and cost-effectiveness of a flexible cystoscope system with a disposable sheath: a randomized clinical trial. *Urol Pract* 4:209–214
9. Doizi S, Kamphuis G, Giusti G, Palmero JL, Patterson JM et al (2017) First clinical evaluation of a new single-use flexible cystoscope dedicated to double-J stent removal (Isiris™): a European prospective multicenter study. *World J Urol* 8:1269–1275
10. Oderda M, Antolini J, Falcone M, Lacquaniti S, Fasolis G (2020) Cost-effectiveness analysis of a single-use digital flexible cystoscope for double J removal. *Urol J* 1:29–34
11. Xuo X, Nardini HK, Ruger JP (2014) Micro-costing studies in the health and medical literature: protocol for a systematic review. *Syst Rev* 3(1):1–7
12. Larsen S, Kalloo A, Hutfess S (2019) The hidden cost of colonoscopy including cost of reprocessing and infection rate: the implications for disposable colonoscopes. *Gut* 2:197–200
13. Ofstead C, Quick M, Eiland J, Adams S (2017) A Glimpse at the true cost of reprocessing endoscopes: results of a pilot project
14. Burke DM, Shackley DC, O'Reilly PH (2002) The community-based morbidity of flexible cystoscopy. *BJU Int* 4:347–349
15. Beebe SC, Jenkins LC, Posid T, Knudsen BE, Sourial MW (2020) Single-use grasper integrated flexible cystoscope for

stent removal: a micro-costing analysis-based comparison. J Endourol 8:816– 820

16. Lilholt Sørensen B (2018) Comparative study on environmental impacts of reusable and single-use bronchoscopes. Am J Environ Prot 4:55–62

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.