A Comparison of Reusable and Disposable Perioperative Textiles: Sustainability State-of-the-Art 2012

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Contemporary comparisons of reusable and single-use perioperative textiles (surgical gowns and drapes) reflect major changes in the technologies to produce and reuse these products. Reusable and disposable gowns and drapes meet new standards for medical workers and patient protection, use synthetic lightweight fabrics, and are competitively priced. In multiple science-based life cycle environmental studies, reusable surgical gowns and drapes demonstrate substantial sustainability benefits over the same disposable product in natural resource energy (200%–300%), water (250%–330%), carbon footprint (200%–300%), volatile organics, solid wastes (750%), and instrument recovery. Because all other factors (cost, protection, and comfort) are reasonably similar, the environmental benefits of reusable surgical gowns and drapes to health care sustainability programs are important for this industry. Thus, it is no longer valid to indicate that reusables are better in some environmental impacts and disposables are better in other environmental impacts. It is also important to recognize that large-scale studies of comfort, protection, or economics have not been actively pursued in the last 5 to 10 years, and thus the factors to improve both reusables and disposable systems are difficult to assess. In addition, the comparison related to jobs is not well studied, but may further support reusables. In summary, currently available perioperative textiles are similar in comfort, safety, and cost, but reusable textiles offer substantial opportunities for nurses, physicians, and hospitals to reduce environmental footprints when selected over disposable alternatives. Evidenced-based comparison of environmental factors supports the conclusion that reusable gowns and drapes offer important sustainability improvements. The benefit of reusable systems may be similar for other reusables in anesthesia, such as laryngeal mask airways or suction canisters, but life cycle studies are needed to substantiate these benefits. (Anesth Analg 2012;114:1055–66)

Perioperative gowns and drapes are available in reusable or disposable alternatives. Comparison of the reusable and single-use alternatives in the operating room (OR) has focused primarily on gowns, even though these comprise only about 30% of the weight of the surgical textiles used. The criteria for evaluating perioperative gowns and drapes include[1–3] (1) protection of health care workers and patients from surgical site or nosocomial infections, (2) comfort, (3) economics, (4) environmental life cycle analysis, and (5) jobs.

Literature was completely reviewed with Medline and Web of Science using the descriptors surgical gowns, cost of surgical gowns, and reusable versus disposable surgical gowns. The main limitation in the current literature comparing reusables and disposables is the repetition of old, now inadequate citations, which have coalesced into widely held perceptions.[4] The evolution of gowns and drapes, driven by new textile technologies and new required testing standards, means that we must set aside those comparisons of liquid and bacterial protection that do not reflect these changes. We should only use studies that cover current textile products and standards.[1,3,5] The new American National Standards Institute and the Association for the Advancement of Medical Instrumentation (AAMI) issued new testing standards for medical gowns and drapes in 2003.[5] This led to the introduction of gowns and drapes that comply with this standard. Experimental studies before 2000 of liquid and bacterial protection and infection with either reusable or disposables have limited relevance to currently available perioperative textiles. The early but frequently cited studies[6–15] often (1) compared materials now considered obsolete (cotton, cotton/polyester, muslin, pulp), (2) used tests that the Food and Drug Administration and independent laboratories demonstrated to produce inadequate results, (3) lacked transparency in whether similar functionality of the gowns was being studied, and (4) excluded published criticisms of the original results.

It is generally accepted that these older studies do not apply to currently available products.[2,3,16,17] The removal of older studies does not reflect badly on this earlier work, but simply recognizes that these do not apply to currently available products. Older studies also reflect economic, environmental, and manufacturing conditions that may lack relevance to contemporary products. The following discussions are based primarily on contemporary studies in reusable and disposable perioperative textiles. Unfortunately, there are so few recent homogeneous studies of gown and drape technology that quantitative meta-analysis was not feasible. Instead, a qualitative comparison of reusable and disposables was done for categories such as comfort, protection, and economics, using health care experts in these products to capture the central conclusions on similarities and differences.

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Accepted for publication January 23, 2012.

The author declares no conflicts of interest.

Reprints will not be available from the author.

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DOI: 10.1213/ANE.0b013e31824d9cc3

Table 1. Recommendation of Gowns for Various Surgical Conditions (Telford and Quebbeman[22])

Operative site	Surgical conditions[a]: <100 mL of blood loss and <2 h duration	>100 mL of blood loss and >2 h duration
Head and neck	Standard gown	Reinforced gown
Chest	Reinforced gown	Plastic reinforced gown
Abdomen	Plastic reinforced gown	Plastic reinforced gown
Perineum	Reinforced gown	Plastic reinforced gown
Extremity	Reinforced gown	Plastic reinforced gown
Skin and subcutaneous	Standard gown	Plastic reinforced gown

Generally, it appears that a standard gown is level 2, a reinforced gown is level 3, and a plastic reinforced gown is level 4.
[a] Applies to surgeon and surgical assistant; other operating room staff should wear protection 1 level below those designated here.

PROTECTION OF HEALTH CARE WORKERS AND PATIENTS FROM SURGICAL SITE OR NOSOCOMIAL INFECTIONS

Surgical gowns have a critical role in infection control.[3,18] Contemporary uses for and types of gowns and drapes have advanced substantially. Laufman et al.[1] grouped the large number of published surgical site infection risk factors into 5 categories based on earlier studies[16,19,20]: (1) surgical team discipline in aseptic practices, (2) patient health status, (3) preventative drugs and antiseptics, (4) design of the OR and procedures, and (5) protective devices of which gowns and drapes are 1 of 7 devices (sterilization, gas/vacuum, air-handling, mechanical and electrical devices, instrumentation, and gloves) in the OR.

Thus, the actual outcome of protecting patients and health care workers (or the failure of protection as an infection) by means of gowns and drapes is only partially due to the properties of these textiles. This contributes to the challenges of actually attributing infection to reusable or disposable gowns or drapes.

Surgical gown selection should be based on the type of surgery, because this dictates the level of required protection.[3] Lewis and Brown[21] and Telford and Quebbeman[22] list the surgical procedures and different levels of protection that are required, as shown in Table 1, a view shared by others.[16,23] The transition from inpatient to outpatient facilities, and the rapid development of minimally invasive surgery[23] also affect the comparison between reusable and disposable gowns and drapes. Unfortunately, few studies have tested the ability of contemporary gowns and drapes to reduce infection.

The AAMI together with the American National Standards Institute developed new standards[24] for liquid and viral protection with medical textiles, based on anticipated exposure (type of surgery). A 4-level hierarchy for gowns and drapes was used. The highest protection, level 4, uses both liquid and viral (hepatitis B, hepatitis C, and human immunodeficiency virus) penetration tests.[25,26] Next in decreasing order of liquid protection are levels 3, 2, and 1, which follow standards set by the American Association of Textile Chemists and Colorists.[27,28] The level of liquid protection corresponds to resistance to penetration of blood and other body fluids at increasing liquid pressures.

It is necessary that textile comparisons be made at the same level of penetration protection (e.g., reusable level 3 is compared with disposable level 3). This evidence-based comparison[17] is an appropriate basis for selecting perioperative textiles. Informed decisions on single-use versus reusable textiles cannot be made for products with different levels of protection.

Considering the large number of infection factors in the OR,[1] the actual role of gowns and drapes in surgery, and the ability to meet modern standards for control of penetration, there is little difference between currently available reusable versus disposable gowns.[3,16] The Centers for Disease Control (CDC)[29] and others[1] concluded that no data suggest important differences in reusable versus disposable gowns and drapes in preventing surgical site infections.[3] Furthermore, the general lack of any documented incident of bacterial contamination from permeation of a gown barrier reflects the similarity of reusable and disposable textiles in protecting health care workers and patients.[1,2,30,31]

Preferences among health care personnel for disposal products do not reflect the available scientific information and are often based on qualitative marketing claims. It is a challenge to help decision-makers understand the near equivalency of modern reusable and disposable textiles. There is also misconception related to multiple uses of a reusable gown or drape. For reusables, maintenance of permeability protection after each cycle of use[2,32,33] directly addresses the issue of continuing protection. Each gown or drape should be routinely tested by physical inspection and repellency testing. Greater access to the reusable service data showing continued fluid protection can be effective in reducing the concerns among health care workers. In addition, reliable logging systems track the number of uses, permitting removal from service at the specified life time.

COMFORT

Comfort of gown users must be compared for gowns of the same rating (i.e., level 3). Data on comfort measurements are not widely available.[33] However, heat barrier and moisture transmission ("breathability") are quantifiable comfort-related measurements.[21] Other comfort factors such as improper fit, stiffness, noise, and roughness are largely not measured. It is reasonable to assume that these other comfort or appearance factors can be designed into the gown or drape and thus be indistinguishable for disposables and reusables at the same level of protection. Lewis and Brown,[21] using thermal manikins and standard comfort thermophysiologic models,[34,35] showed that 2 reusable and disposable gowns achieved the comfort range for operations exceeding 3 hours, typical for the use of level 4 gowns. All 7 of the reusable and disposable gowns tested were in the core temperature range of comfortable for operations less than 1 hour, now a common occurrence.

Mittermayer et al.[2] examined 16 reusable and 11 disposable gowns. He found for reusables (11 gowns) that 1-, 2-, and 3-ply woven gowns with laminates were in the acceptable to very good comfort range, based on a moisture vapor transmission rate $<8\ m^2\ Pa/W$. Seven disposable gowns of 1- and 2-ply nonwovens with film laminates were in the same comfort range (moisture vapor transmission rate $<8\ m^2\ Pa/W$). These quantitative measurements of comfort were comparable for disposable and reusable products.

Conrady et al.[36] used a more rigorous, user-comparative effectiveness study of reusable and disposable gowns worn by surgeons and surgical technicians. The surgical teams conducted 119 surgical procedures in 2 hospitals and compared both types of gowns by wearing each type in various procedures. This is the only direct evidence-based study of gown comfort currently reported. The gowns were generally level 2 and 3 gowns, based on whether it was minor or major surgery, respectively. Surgeons and technicians rated the reusable gowns as more comfortable.

For gown comfort, the available field data and anecdotal discussions with manufacturers and users suggest that current reusable gowns, at level 2 and 3 as typical of short procedures, are more comfortable than disposable gowns. At level 4 or in long procedures, reusable gowns with breathable laminates are more comfortable than disposable gowns.

ECONOMICS

Economic comparisons of perioperative reusable and disposable textiles often include unspecified factors, making quantitative comparison difficult.[1,3,4,7,37,38] Also, laundry and sterilization at many large hospital facilities are now provided by an external vendor, rather than performed in-house. Approximately 1% of the hospitals with reusable perioperative textiles process these in-house (personal communication, J. Hamilton, SRI Surgical, 2010). This might make economic comparison easier because purchase and contracts are distinct costs, but that has not been evident in published studies.

A major difference between reusables and disposables has been the purchasing systems for these products. Reimbursements to hospitals for volume of purchases (of which gowns and drapes are not a large percentage) are characteristic of the disposable market. These cash flows are often not transparent, nor do these necessarily accrue to the departments needing the gowns and drapes. Reusables are more often provided on an annual or multiyear service contract. Thus, a comprehensive multiyear evaluation of disposables versus reusables has not been performed, and is unlikely to occur.

There are only 3 published economic studies of contemporary surgical gowns, all non-United States (US). In conducting a comprehensive purchasing study in Turkey, Baykasoglu et al.[38] found that the cost of reusable gowns ($8 per surgical package) was approximately 25% of the cost of disposable gown costs ($33 per surgical package). Lizzi et al.,[39] conducting a study in an Argentinean hospital, found that reusables cost $16 per surgical package, whereas disposables cost $9 per surgical package. Martec Corporation, a Canadian engineering firm, studied the use of gowns at the National Health Service in the United Kingdom.[40] They found disposables were 4% lower in cost than reusables, which was within the margin of error of the study. No detailed multihospital economic study is available. The lack of clear data in either direction suggests that reusable and disposable surgical gowns and drapes are probably similar in costs with most variations attributable to local contract negotiations.

Cost differences between reusables and disposables may be overshadowed by personnel preferences. This would explain the higher reusable use percentages in Europe (50%) versus the US (10%),[41] rather than any fundamental cost differences. Neither disposable nor reusable systems have eliminated the other product type. This suggests similar costs because significant cost differences would have driven the market to essentially zero for the expensive option.

Many hospitals undertake economic analyses before product purchase. Unfortunately, there is no independent access to these data. One can only look at the market and conclude that because both reusable and disposable surgical gowns and drapes remain on the market, these costs must remain competitive. Lastly, the ideal mix may not be exclusively reusable versus disposable textile. Laufman et al.[1] anticipated the evolution of hybrid surgical packages, which are now in the market, in which specific reusable and disposable items are selected based on economic and environmental factors, creating a more sustainable surgical package.

ENVIRONMENTAL LIFE CYCLE ANALYSIS

Life cycle inventory is the quantitative measurement of energy and emissions (known as a life cycle inventory) that occurs in the manufacture, use, and disposal of surgical gowns and drapes. This encompasses all aspects from oil and ore to the finished gown or drape, the cleaning and sterilizing of reusable products, and the final end-of-life stage for reusables and disposables. Life cycle impact assessment is the quantification of each environmental impact, such as carbon footprint, human toxicity, and stream eutrophication, based on the life cycle inventory results.

During the use and at the end-of-life stage, surgical wastes (blood, tissue, fluid) are produced for both disposable and reusable gowns and drapes. The surgical waste and disposable gowns are either sent to landfills, where only the surgical waste degrades (modern gowns are essentially inert), or incinerated, where the majority of carbon is converted to carbon dioxide. Currently, landfill is the dominant route for disposables and is analyzed in these life cycle studies. Reusable gowns are washed to produce laundry wastes that are treated to achieve receiving water standards. Reusable gowns at end-of-life are typically transferred to other uses (less developed countries or alternative applications) and thus only the treatment of the surgical waste (blood, tissue, fluid) is included.

In 1998, the CDC hypothesized that there were no differences in life cycle impacts between reusable and disposable gowns.[29] Since 1993, there have been 5 life cycle studies of protective surgical gowns and 1 study of worker coveralls in nuclear power plants.[11,42–46] These studies do not support the CDC hypothesis conclusion. These life cycle studies typically compare a fixed number of disposable gowns (typically 50–75) with a single reusable gown used 50 to 75 times. As a result, these studies compare the manufacturing, sterilization, and transport of disposables to the manufacture, laundry, sterilization, and transport cycles for reusables. These studies show that the environmental impact of transport for reusables is modest. For example, in the Environmental Clarity report,[46] transport accounts for <2.2% of overall gown life cycle energy at 1000 miles per laundry cycle.

Analysis of life cycle data is often limited by the amount of transparent information in the reports. This does not suggest that the conclusions are flawed, but simply that most published studies lack the quality of life cycle data reporting required for quantitative analysis of perioperative textiles.

Table 2 provides a comparison of the disposable and reusable systems covered by each of the 6 life cycles, whereas Table 3 shows the results of these studies. Table 4 documents the life cycle factors missing from each study. All 6 life cycle studies found that the reusable system provided substantially better environmental profiles than single-use systems. Selecting disposables instead of comparable reusables increased energy use and carbon footprint by 200% to 300%, increased the water footprint by 250% to 330%, and increased solid waste from 38 kg to 320 kg per 1000 gown uses (a 750% increase).

THE MCDOWELL STUDY

The oldest life cycle study is the comparison by McDowell[11] of a woven polyethylene terephthalate (PET) reusable gown and lap drape used over 75 cycles and a single-use disposable spunlace PET (50%)/wood pulp (50%) nonwoven gown and lap drape. This 15-page report was published in 1993, but the detailed data remain unavailable. The study basis was 1 surgical procedure in which 3.7 gowns and 1.2 lap drapes were used. The report does not state the protection desired by the gown user, but the gowns appear to be a level 2. The gowns predate the AAMI standards for liquid protection and the advent of modern gowns meeting these standards. The weight of these gowns and drapes was not provided and so other comparative calculations were not possible. The report does not provide data on the supply chain and manufacturing processes of the disposable and reusable gowns.

Despite these limitations, the report by McDowell is frequently cited to support the claim that the manufacturing of the reusable gown produces higher volatile organic chemical (VOC) emissions (a part of the photochemical ozone impact category) from dyeing and finishing compared with disposables. Because both the disposable and reusable systems use PET, it is unclear why the dyeing and finishing for a given color (such as pink or blue) should be substantially different. Because the reusable is dyed only once per 75 uses, whereas the disposables are dyed 75 times for the same 75 uses, the VOC emission difference is even less clear. Two later studies evaluated VOC emissions and found that manufacturing of disposable gowns produced 4 to 5 times larger VOC emissions than the manufacturing of reusable gowns.[43,44] It would seem that citing the McDowell life cycle study as having greater VOC for reusable gowns and drapes is inconsistent with the mutual use of dyeing PET and the entire supply chain aggregation of VOC measured as a photochemical ozone impact category.

McDowell reports the reusable perioperative textile water use as 3.9 gallons per gown and 10.7 gallons per lap drape, far more than the 0.14 gallons per gown and 0.93 gallons per lap drape required for disposables. The report does not distinguish water required in manufacturing from water required for laundry and sterilization, precluding comparison with other life cycle studies. As shown in Table 3, subsequent comparisons of water use in the manufacturing of disposable gowns by the Royal Melbourne Institute of Technology (RMIT), the European Textile Service Association (ETSA), and Environmental Clarity suggest that McDowell underestimated the water use by a factor of 13 to 800. Therefore, McDowell's water estimates are likely incorrect. Any of the corrected factors for water would indicate more water use by disposables than reusables. Gown sterilization is discussed as a health risk factor by McDowell, but does not appear to be in the environmental life cycle. The report showed that higher energy was needed for the disposable system (20 megajoule [MJ]/gown and 42.5 MJ/lap drape) than the reusable system (5.8 MJ/gown and 11 MJ/lap drape).

THE ETSA STUDY

The ETSA conducted a life cycle study published in 2000.[42] The functional unit of comparison was 1 reusable gown (woven PET and Gore laminate) with disposable primary packaging versus 1 disposable gown (nonwoven 50 wt% PET and 50 wt% wood pulp) and a low-density polyethylene barrier film plus disposable primary packaging, as shown in Table 2. No gown protection standard was cited, but from the general description, the reusable gown was probably level 3 and the disposable gown between levels 2 and 3. The reusable gown was laundered for 75 cycles. Transport for the reusables and disposables was specified. This report had a moderate amount of transparency, but was often unclear in units (e.g., kg reusable gowns was used, but in some instances appeared to be soiled gown and other places clean gown, a significant difference in weight). Few data on manufacturing and process are shown. An older reusable gown with cotton and PET was also studied, but because it is not currently meeting AAMI level 2, 3, and 4 standards, this gown was not included in this review.

The ETSA report was the first to identify that greater water use occurs in the manufacture of disposable gowns compared with the water used in laundry and sterilization of a reusable gown, as shown in Table 3. The purpose of the water use in the supply chain of either gown was not given. The energy for the supply chain, manufacture, use, and end-of-life of the reusable gown system (75 cycles) was lower (11–15 MJ/gown) than that of the disposable gown (75 gowns) (29–35 MJ/gown). The reusable gowns required 42% less energy and 32% less water than disposable gowns, as shown in Table 3.

THE RMIT STUDY

The RMIT University conducted a life cycle inventory study published in 2008.[43] They used the surgical package as a functional unit, although it was only the most basic package (gown and towel). The reusable gown was between a level 2 and level 3, whereas the disposable was probably a level 3. The reusable gown and towel were assumed to be usable for 127 cycles. This is significantly higher than the 50 to 75 cycles found in current practices where testing for AAMI compliance standards is used. Their sensitivity analysis showed that their overall energy differences were still present at 50 cycles, but the 127 cycles

Table 2. Descriptions of Life Cycle Inventory Studies of Reusable and Disposable Textiles

	McDowell[11] (1993)	ETSA[42] (2000)	RMIT[43] (2008)	MnTAP[44] (2010)	UniTech[45] (2010)	Environmental Clarity[46] (2010)
Reusables	1 surgery, 3.7 gowns, and 1.2 lap drapes, washed 75 cycles	1 large gown, woven level 3 or 4, washed 75 cycles	1 surgical package, washed 127 cycles	1 gown washed 50 cycles	1 gown for nuclear power plant radiological protection, 100 cycles	1000 level 3 gown uses, washed 75 cycles
	1 large gown, woven PET, likely level 2	546 g = 389 g PET and 157 g Gore material modeled as polyurethane	1 gown, woven (94% PET/6% cotton) (between a level 2 and level 3), 287 g	1 large gown, woven PET with polyethylene laminate, 407 g, level 3	Woven nylon, weight not given	Critical areas, Gore fabric; noncritical areas, woven PET: 1 gown 0.49 kg
	1 lap drape, woven PET		Cotton towel, 73.5 g Disposable paper autoclave indicator tape, 5 g			
Primary disposable packaging	Not defined		Polypropylene nonwoven CSR wrap, 12.8 g	Not defined	Not defined	Paper CSR wrap and insert, 22.3 kg
		Disposable paper and LDPE, 58 g	Outer bag, half paper half HDPE, 14.9 g			EMAC outer bag, 12.5 kg
Secondary disposable packaging						LDPE bag, 0.33 kg
Tertiary disposable packaging						LDPE film, 0.0033 kg
	Not given	Total 604 g (1.33 lb.)	Total 393.7 g (0.87 lb.)	Total 407 g (0.9 lb.)	411 (0.91 lb.)	Total 490 kg (1100 lb.)
Disposables	1 large gown, spunlace 50% PET, 50% wood pulp	1 large gown, nonwoven level 3 or 4	1 surgical package	1 large gown, polypropylene nonwoven, 137 g, level 3	1 gown for nuclear power plant radiological protection, single-use	1000 level 3 gowns
		230 g = 104 g paper pulp, 104 g PET, 22 g LDPE film	1 gown (approximately level 3), nonwoven polypropylene, 222 g Paper towel, 13.9 g		Nonwoven polyvinyl alcohol	critical areas, polypropylene film; noncritical areas, SMS PET: 1 gown 0.243 kg
Primary disposable packaging	Not defined	Not defined	Nonwoven polypropylene CSR wrap, 12.8 g	Not defined	Not defined	SSMS PP CSR wrap, 22.1 kg Inset paper, 3.1 kg
		Paper and LDPE, 58 g	Outer bag, half paper and half HDPE, 21.9 g			LDPE outer bag, 13.9 kg
Secondary disposable packaging						LDPE bag, 3 kg; boxboard 35 kg
Tertiary disposable packaging						LDPE film, 0.33 kg
	Not given	Total 288 g (0.63 lb.)	Total 271 g (0.60 lb.)	Total 137 g (0.3 lb.)	266 g (0.59 lb.)	Total 243 kg (535 lb.)
Allocation	Not defined	Mass in most places, system expansion for recycle of disposables	Mass allocation inferred from the databases cited	Mass allocation inferred from the databases cited	Literature values, so mass allocation is assumed	Mass allocation
Transport loop						
Reusable	Not defined	Ship to Europe (20, 000 km), truck to hospital (3000 km), truck to laundry (200 km)	Truck in China (100 km), ship to Melbourne (9617 km), truck to manufacturer (30 km), truck to laundry (30 km)	Truck from manufacture to hospital (2000 km)	Not defined	Fabric movement in US (3320 km) to Mexico and return (959 km) to distribution in US (2800 km), all truck

(*Continued*)

Table 2. (Continued)

	McDowell[11] (1993)	ETSA[42] (2000)	RMIT[43] (2008)	MnTAP[44] (2010)	UniTech[45] (2010)	Environmental Clarity[46] (2010)
Disposable	Not defined	Not defined	Ship NY to Honduras (3165 km), ship to Melbourne (18, 757 km), truck to distribution warehouse (30 km), truck to hospital (50 km)	Truck from manufacturer to port (800 km), ship to port (11, 670 km), rail to hospital (2870 km)	Not defined	Truck in China (800 km), ship to US (11, 700 km), distribution in US (2200 km)
End-of-life						
Reusables	Incineration with energy recovery	Landfill	Packaging landfill	Incineration	Not defined	Reuse as gown outside US; wastewater treatment of surgical wastes
Disposables	Incineration with energy recovery	Landfill	Packaging and gown landfill	Incineration	Dissolution, Fig. 2	Landfill of gown and surgical waste, gas capture
Other items included in life cycle						
Reusables						Water for laundry/sterilization and manufacturing
Disposables						Water for manufacturing; ethylene oxide for sterilization; lost instruments from surgery

PET = polyethylene terephthalate; ETSA = European Textile Service Association; RMIT = Royal Melbourne Institute of Technology; MnTAP = Minnesota Technical Assistance Program; CSR = central sterile room; LDPE = low-density polyethylene; HDPE = high-density polyethylene; EMAC = ethyl methacrylate copolymer; SMS = spun bond-melt blown-spun bond; SSMS PP = spun bond-spunbond-melt blown-spun bond polypropylene; NY = New York; US = United States.

are used in this review because most of their results are for this functional unit, as shown in Table 3. The RMIT report had greater transparency than the previous 2 studies, but it is limited to the discussion of the laundry and sterilization of reusable gowns. The surgical package with 2 items was not separated to provide the reader with specific gown and towel data. This is a particular problem because the gown and towel (for both disposable and reusable) are made from different materials. Most data are in percent of total energy, but the actual total is never given. In addition, detailed information on laundry and sterilization are given per kilogram fabric, but the units of the summary are per surgical package and it is unclear how these transformations of data were done.

The RMIT study found that reusable textiles, after 127 cycles, required less water (2.9 gallons per gown and towel) than disposable textiles (3.7 gallons per gown and towel), giving similar results as ETSA, as shown in Table 3. Using their sensitivity analysis, the water use of the reusable and disposables was approximately equal at 75 to 85 cycles, the more typical reuse range for such systems, although the details of the water use for the disposable supply chain were not presented. The energy use could only be quantified by back-calculating from the CO_2 (global warming) emissions, a clear example of low transparency. The reusable surgical package had lower energy requirements (8.5 MJ/gown and towel) than the disposable system (16.6 MJ/gown and towel), as shown in Table 3. RMIT determined the cumulative VOC emissions for these 2 surgical packages, when expressed as photochemical oxidation impact normalized as ethylene. The disposable surgical package was 0.46 g photochemical oxidation per surgical package, whereas the reusable was 0.16 g photochemical oxidation per surgical package, a substantially different result from the early McDowell life cycle study. The soiled gown weight compared with the clean gown was estimated by the authors and was given as 2.6 kg soiled gown/kg clean gown. This is approximately 100% larger than recent direct measurements.[46]

THE MINNESOTA TECHNOLOGY ASSISTANCE PROGRAM STUDY

Van den Berghe et al.[44] at the Minnesota Technology Assistance Program reported a life cycle study in 2010. The comparative systems were a reusable woven PET gown with low-density polyethylene laminate and a nonwoven polypropylene gown, both level 3, as shown in Table 2. The reusable gown was cycled 50 times. This study is not readily available as a report and so only slides from presentations are available for use. Results are expressed in CO_{2eq} emissions, thus these were back-calculated to estimate energy in MJ. As a result, this study currently has low transparency and very limited detailed results.

The study by the Minnesota Technology Assistance Program cataloged energy for these 2 gowns. The reusable gown was noticeably lower in life cycle energy (4 MJ/gown) than the disposable gown (13 MJ/gown). No water evaluations were included. VOC emissions were 5 times higher with disposable gowns than reusable gowns. This supports the RMIT life cycle results and does not support the McDowell life cycle results.

Table 3. Comparative Results of Life Cycle Inventory Studies of Reusable and Disposable Textiles

	McDowell[11] (1993)	ETSA[42] (2000)	RMIT[43] (2008)	MnTAP[44] (2010)	UniTech[45] (2010)	Environmental Clarity[46] (2011)
Reusables	Package, 3.7 PET gowns; 1.2 PET lap drapes, 75 cycles (no masses given); likely level 2	Gown: PET/PU (0.546 kg) 75 cycles; between level 3 and 4	Package: PET/cotton gown (0.287 kg), cotton towel (0.074 kg), 127 cycles; between level 2 and 3	Gown: PET with PE film (0.41 kg), 50 cycles; level 3	Gown for nuclear power plant radiological protection, woven nylon (0.41 kg), 100 cycles	Gown: critical areas Gore fabric, noncritical areas woven PET, 75 cycles; level 3 (0.49 kg)
		Process energy values	Process energy values			Process energy values, all based on gown use
Washer		3.2 MJ natural gas/kg clean gown, 80°C, Table 4 and Fig. 10	5.4 MJ natural gas/kg clean linen, 80°C Table 4-6			Energy improvement laundry, 1.5 MJ natural gas/kg clean gown: conventional laundry, 5 MJ natural gas/kg clean gown
		0.3 MJ electricity/kg clean gown (based on 1.55-lb. soiled linen/lb. clean linen), Table 4	0.18 MJ electricity/kg clean linen			Energy improvement laundry, 0.6 MJ electricity/kg clean gown: conventional laundry, 0.6 MJ electricity/kg clean gown
Washer water use		17.3 kg/clean gown = 2.5 gal./lb. soiled linen (based on 1.55-lb. soiled linen/lb. clean linen), Table 8	1.6 gal./lb. soiled linen based on 40% recycle of 2.7 gal./lb. soiled linen, Table 4-6		3.4 gal./lb. clean gown	2.36 gal./lb. soiled laundry = 3.6 gal./lb. clean gown
Dryer		6.6 MJ/clean gown = 12.0 MJ natural gas/kg clean gown, Table 5	3.1 MJ natural gas/kg clean linen, Table 4-8			Energy improvement laundry, 10 MJ natural gas/kg clean gown: conventional laundry, 10 MJ natural gas/kg clean gown
		0.36 MJ electricity/gown, 0.66 MJ electricity/kg clean gown	0.18 MJ electricity/kg clean linen			Energy improvement laundry, 0.4 MJ electricity/kg clean gown: conventional laundry, 0.4 MJ electricity/kg clean gown
Total laundry		15 MJ natural gas/kg clean gowns, based on 1.55-kg soiled/kg clean gown	8.5 MJ natural gas/kg clean linen, summation		3–4 MJ/kg gown	Energy improvement laundry, 12.6 MJ natural gas/kg clean gown: conventional laundry, 15 MJ natural gas/kg clean gown
		0.85 MJ electricity/kg clean linen	0.36 MJ electricity/kg clean linen			Energy improvement laundry, 1 MJ electricity/kg clean gown: conventional laundry, 1 MJ electricity/kg clean gown
Steam sterilization		0.54–4.8 MJ natural gas/kg clean linen	1.8 MJ natural gas/kg clean linen, Table 4-10		Not needed	0.44 MJ natural gas/kg clean gown
			0.09 MJ electricity/kg clean linen, Table 4-10			0.063 MJ electricity/kg clean gown
Steam sterilization water use			1.9 gal. water/lb. clean linen, Table 4-10			0.02 gal. water/kg clean linen
Wastewater treatment			0.072 MJ electricity/kg soiled linen (0.032 MJ/lb. soiled linen), Table 5-15			1.2 MJ electricity/kg soiled linen

(*Continued*)

Table 3. (*Continued*)

	McDowell[11] (1993)	ETSA[42] (2000)	RMIT[43] (2008)	MnTAP[44] (2010)	UniTech[45] (2010)	Environmental Clarity[46] (2011)
End-of-life of surgical pack or gown	Incineration with energy recovery	Incineration	Landfill	Incineration	Not included	Reused
Results		Natural resource energy[a]	Natural resource energy[a]	Natural resource energy[a]	Natural resource energy[a]	Natural resource energy[a]
Manufacture, new gown		180 MJ/kg gown, Fig. 10	1.45 MJ/gown plus towel 127 cycles = 180 MJ/surgical gown plus towel = 410 MJ/kg surgical gown plus towel, from Table 0-1 and % from Fig. 6-1	78 MJ/gown = 190 MJ/kg gown	86 MJ/gown = 209 MJ/kg gown	240 MJ/kg gown
Wash			2.3 MJ/surgical pack = 5.8 MJ/kg surgical pack		Table 2	
Dry			1.35 MJ/surgical pack = 3.4 MJ/kg surgical pack			
Sterilize			1.35 MJ/surgical pack = 3.4 MJ/kg surgical pack			
Total laundry/sterilization		23.5 MJ/kg gown	12.6 MJ/kg surgical pack	5.6 MJ/kg gown (no sterilization)		Energy improvement, 17.7 MJ/kg clean gown: conventional, 21.9 MJ/kg clean gown
Polypropylene CSR wrap manufacture			0.78 MJ/surgical pack = 2 MJ/kg surgical pack			0.67 MJ/clean gown = 1.4 MJ paper CSR/kg clean gown
Outer bag, half paper, half HDPE			0.5 MJ/surgical pack = 1.3 MJ/kg surgical pack			0.56 MJ/clean gown = 1.1 MJ EMAC outer wrap/kg clean linen
Transportation, new gown	Not included	1.9 MJ/kg gown	Incomplete	13.9 MJ/kg gown		14 MJ/kg clean gown
Energy for functional unit	5.8 MJ/gown, 16 MJ/drape	11.4–14.9 MJ/gown, 21–27 MJ/kg gown, Table 1	8.5 MJ/surgical pack = 22 MJ/kg surgical pack, summation	4 MJ/gown, 9.8 MJ/kg gown	220 MJ/gown	11.9 MJ/clean gown = 24 MJ/kg clean gown
Water		11–17 kg/gown = 2.9–4.5 gal./gown = 2.2–3.4 gal./lb. gown, Table 14	11 kg/gown and towel = 2.9 gal./gown and towel = 3.3 gal./lb. gown and towel			0.38 kg/clean gown = 0.2 gal./kg clean gown
Disposables	Package, 3.7 50% pulp, 50% spunlace PET gown, 1.2 50% pulp, 50% spunlace PET lap drape	Gown: PET/pulp (0.23 kg)	Package: PP (0.222 kg)/paper towel (0.014 kg)	Gown: polypropylene nonwoven (0.14 kg); level 3	Gown for nuclear power plant radiological protection, polyvinyl alcohol nonwoven (0.27 kg)	Gown: critical areas polypropylene film, noncritical areas SMS PET; level 3 (0.24 kg)
Results		Natural resource energy	Natural resource energy	Natural resource energy	Natural resource energy	Natural resource energy
Manufacture		120–130 MJ/kg gown	15.2 MJ/surgical pack = 56 MJ/kg surgical pack, from Table 0-1 and % on Fig. 6-5		57.5 MJ/gown = 430 MJ/kg gown	19.5 MJ/gown = 80 MJ/kg clean gown

(*Continued*)

Table 3. (*Continued*)

	McDowell[11] (1993)	ETSA[42] (2000)	RMIT[43] (2008)	MnTAP[44] (2010)	UniTech[45] (2010)	Environmental Clarity[46] (2011)
CSR wrap			Polypropylene, 0.9 MJ/surgical pack = 3.3 MJ/kg surgical pack			PP SMS, 1.5 MJ/clean gown = 6 MJ/kg clean gown
Outer bag			Half paper and half HDPE, 0.52 MJ/surgical pack = 1.4 MJ/kg surgical pack			LDPE, 0.47 MJ/clean gown = 1.9 MJ/kg clean gown
Transportation	Not included	2.6 MJ/kg gown	Incomplete	6.8 MJ/kg clean gown	Not included	20 MJ/kg clean gown
End-of-life of surgical package or gown		Incineration	Landfill	Incineration	Dissolution and wastewater treatment	Landfill
Energy for functional unit	20 MJ/gown, 42.5 MJ/drape	28–35 MJ/gown, 120–150 MJ/kg gown, Table 1	16.6 MJ/surgical pack = 61 MJ/kg surgical pack	13 MJ/gown, 95 MJ/kg gown	6050 MJ/gown	22.5 MJ/gown = 92.5 MJ/kg clean gown
Water		43 kg/gown = 11.5 gal./gown = 18 gal./lb. gown	14 kg/gown and towel = 3.7 gal./gown and towel = 6.2 gal./lb. gown and towel, Table 5-1		49 gal./lb. clean gown	0.8 kg/gown = 3.3 kg/kg clean gown = 0.4 gal./lb. gown
Environmental reduction when selecting functional unit of reusable system, expressed as % of functional unit of disposable system (based on values per gown or functional unit)	29% gown and 38% lap drape	42% nre; 32% water	51% nre, 78% water	31% nre	3.6% nre, 7% water	53% nre; 48% water

PET = polyethylene terephthalate; PE = polyethylene; ETSA = European Textile Service Association; RMIT = Royal Melbourne Institute of Technology; MnTAP = Minnesota Technical Assistance Program; MJ = megajoule; HDPE = high-density polyethylene; CSR = central sterile room; EMAC = ethyl methacrylate copolymer; PP SMS = polypropylene spun bond-melt blown-spun bond; LDPE = low-density polyethylene.

[a] nre = natural resource energy; process energy is converted to nre using factor for delivering fuel to point of use and factor for energy generated per MJ fuel, natural gas factor 1.15, electricity factor 3.44.

Table 4. Listing of Factors that Appear Missing in Life Cycle Studies of Reusable and Disposable Medical Textiles

Missing elements	McDowell[11] (1993)	ETSA[42] (2000)	RMIT[43] (2008)	MnTAP[44] (2010)	UniTech[45] (2010)	Environmental Clarity[46] (2011)
Manufacture of fabric life cycle	X			X		
Cut-sew-trim assembly	X	X		X		
Transport	X	X (unclear transport in supply chain of disposables)				
Sterilization	X	X (disposables)	X	X (disposables)		
End-of-life	X	X (reusable)			X (reusable)	
Capital equipment	X	X	X		X (reusable)	X
Packaging	X (primary and secondary)	X (secondary and tertiary)			X (primary and secondary)	
Wastewater treatment	X	X		X	X	
Dyeing and finishing		X	X	X		

ETSA = European Textile Service Association; RMIT = Royal Melbourne Institute of Technology; MnTAP = Minnesota Technical Assistance Program.

THE UNITECH CORPORATION STUDY

A fifth life cycle study was completed in 2010 by UniTech.[45] This study examined worker coveralls in nuclear power plants. These gowns do not require water permeation protection, and are thus more like medical contact precaution garments. The reusable gown is made of woven nylon, whereas the disposable gown is of polyvinyl alcohol, 2 very different fabrics from surgical gowns. The reusable gown was evaluated for 100 uses. The disposable gown is dissolved at end-of-life and managed as a liquid. In addition, no sterilization is required.

The energy life cycle comparison they completed showed 6050 MJ/gown for the disposable and 220 MJ/gown for the reusables. The water use for the reusables was 3.4 gallons/gown whereas the disposables was 49 gallons/gown. The details of water use in the supply chain were not provided.

THE ENVIRONMENTAL CLARITY STUDY

Environmental Clarity completed a life cycle study in 2011.[46] The functional unit was 1000 uses of level 3 gowns, which means 13.3 gowns were manufactured and laundered/steam sterilized 75 cycles to give a total of 1000 reusable gown uses. For the disposable system, 1000 gowns were manufactured and sterilized using ethylene oxide. The manufacturing of the reusable gown had in the critical zones of the gown a trilaminate of woven or knitted PET with a center layer of a breathable barrier film modeled after a breathable barrier film involving a 3-layer laminate with an expanded polytetrafluoroethylene film. In the noncritical zone, a woven PET fabric was used. For the disposable level 3 gown, the critical zone was spun blown-melt bond-spun blown PET with a polypropylene film barrier. This same material, without the polypropylene film barrier, was used in noncritical zones.

A separate laundry and sterilization system was analyzed for the reusable gown. Data were used for an energy-improved laundry/sterilization system and for a conventional laundry/sterilization because this is the largest contributor to the reusable gown system. For the disposable system, each gown was sterilized with ethylene oxide and the supply chain for ethylene oxide was also included.

The surgical waste (fluid, tissue, blood) was measured in the field. For the reusable gowns, the life cycle inventory includes this organic load (chemical oxygen demand) as treated in the aerobic municipal wastewater treatment plant. This life cycle inventory block included the energy and waste to return the nonevaporated water part (97.75%) of the laundry/sterilization water to regulatory-permitted condition and thus was not counted as water consumed. The reusable gown, after 75 cycles, was routinely transferred to developing countries and used as a surgical gown.

The same mass of surgical waste per gown or drape was used in the disposable system and transferred to an anaerobic landfill, where it undergoes degradation to create methane and carbon dioxide. A general US profile of gas capture and no gas capture at landfills was used to assess the impact of the degradation of the surgical waste in this life cycle inventory. The disposable gown is essentially nondegradable polymer and so only the energy of landfilling a unit weight of gown plus decomposition of surgical waste were included.

Medical instruments are routinely lost in the OR after the patient leaves. These were measured in the field. In the case of reusables, these were returned to the health care facilities. However, in the disposables life cycle inventory study, these instruments were manufactured as replacements for the instruments that were lost to the landfill. The life cycle inventory of these instruments was added to the disposables case.

The study also included the transportation of all the chemicals in the supply chain as well as the fabric going to cut, sew, and trim during manufacturing and then to the hospitals as separate items for both reusable and disposable life cycle inventory.

The energy of the full cradle-to-end-of-life analysis of the 1000 disposable gown uses (1000 gowns) was 22,500 MJ, whereas for the 1000 reusable gown uses (13.3 gowns laundered 75 times) of the reusable system, the energy was 11,900 MJ. Similarly, the water use (not returned to surface water, known in the water footprint literature as blue water) for the 1000 gown uses was 800 kg for the disposable gowns and 385 kg for the reusable gowns.

Direct life cycle measurement of the manufacture for radiofrequency identification (RFID) devices to track the number of reusable cycles was not made, but a published literature source for a 32-MB DRAM chip was found.[47] The life cycle for the microchip was 40 MJ/chip, which for 1 RFID per gown is 40 MJ/reusable gown/drape. Using the transparent Environmental Clarity life cycle analysis, the basis of 1000 gown uses is 12,530 MJ with RFID (before accounting for chip recycle) versus 22,500 MJ/1000 disposable gown uses. Without the life cycle of the RFID chip, the respective energy values are 11,900 MJ and 22,500 MJ, thus indicating that the tracking feature does not substantially change the life cycle results. In addition, the RFID tracking chips are virtually 100% recycled into new gowns and drapes (no observable loss in RFID function over 2 decades). Therefore, the greenhouse gas effect of these RFIDs on the gown or drape carbon footprint or other environmental impacts is essentially zero.

For the environmental life cycle, the 6 studies on reusable versus single-use gowns and drapes present a consistent set of results. There is a significant life cycle difference between these alternatives. First, when comparing reusables with disposables, the energy requirement for reusable perioperative textiles is approximately 30% to 50% of the energy (expressed as natural resource energy, which is the sum of all fuel energy needed to deliver energy to the point of use, convert the fuel into usable energy, and consume the energy in the manufacturing or other processes). Said differently, the disposables are 200% to 300% higher in energy usage. When water use needed in manufacturing is added to water required for laundry and sterilization, disposable textiles consume 250% to 330% more water than comparable reusable textiles. Only the earliest life cycle inventory study deviates from these findings,[11] but that study is compromised by numerous errors that are corrected by the evidence of the other independent life cycle inventory results. Specifically, the volatile organic carbon emissions and water consumption are in fact lower with reusable systems than reported by McDowell[11] for the 1993 study. The transparent database of the Environmental Clarity study[46] has improved life cycle analyses of single-use and reusable surgical textiles, and will help identify hybrid (reusable and disposables combined) surgical packages to provide the health care market with the best alternatives.

JOBS

An interesting comparison of reusable and disposables has been the relation to jobs and employment.[2,38,48] However, no comprehensive study of jobs for reusable and disposable alternatives was found at this time. Those studies that included local jobs as a factor in comparing reusable and disposables identified that reusable laundry, assembly, and transport steps provided more jobs than the disposable alternatives. Mittermayer[2] even classified the jobs as local and hence an attribute to differentiate the gown and drape alternatives. At this time, because there are no comprehensive labor studies, this current review only identifies jobs as a potential dimension for comparisons of reusables and disposables.

CONCLUSION

Reusable and disposable gowns and drapes meet new standards for medical workers and patient protection, use synthetic lightweight fabrics, and are competitive in price. Reusable surgical textiles offer substantial sustainability benefits over the same disposable product in energy (200%–300%), water (250%–330%), carbon footprint (200%–300%), volatile organics, solid wastes (750%), and instrument recovery. This has now been verified in all 6 available life cycle studies. Other factors including cost, protection, and comfort are reasonably similar. The large environmental sustainability benefits of reusables allow nurses, physicians, and hospitals to make substantial improvements for this industry. It is no longer valid to indicate that reusables are better in some environmental impacts and disposables are better in other environmental impacts. The uniformity of life cycle results from multiple studies over the past decade may reduce the need for future studies of perioperative textiles and shift interest to other reusable OR medical products, such as laryngeal mask airways and suction canisters.

DISCLOSURES

Name: Michael Overcash, PhD.
Contribution: This author designed the study, conducted the study, analyzed the data, and wrote the manuscript.
Attestation: Michael Overcash approved the final manuscript.
This manuscript was handled by: Steve L. Shafer, MD.

ACKNOWLEDGMENTS

This study was designed with input from a team of firms responsible for surgical disposables and reusables (Lac-Mac, Medline, W. L. Gore & Associates, and SRI Surgical). Funding was from W. L. Gore & Associates and SRI Surgical. This review was substantially improved by inputs from the Association of the Nonwoven Fabrics Industry (INDA), Textile Rental Services Association of America (TRSA), and the American Reusable Textiles Association (ARTA). The perspective of both the single-use and the reusable communities has been committed to scientific, transparent results.

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