ORIGINAL RESEARCH

Spectroscopic analysis of metal contents in mosquito nets used in hernia repair surgery

Hannah L. Peterson[1], Elizabeth L. Peterson[1], Rachael A. Bouwman[1], Kumar Sinniah[1], Bruce C. Steffes[2], Jason Fader[3]

1. Department of Chemistry & Biochemistry, Calvin College, Grand Rapids, MI, USA
2. Department of Surgery, Loma Linda University, Loma Linda, CA, USA
3. Kibuye Hope Hospital, Kibuye, Burundi

Correspondence: Prof. Kumar Sinniah (ksinniah@calvin.edu)

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Abstract

Background
This study aimed to quantitatively evaluate the heavy metal content of several types of mosquito nets used in hernia repair surgery and to determine whether autoclave sterilization weakens the mosquito net material.

Methods
We extracted the metallic contents of a commercial polypropylene surgical mesh as well as polyester, low density polypropylene, and polyethylene mosquito nets via a wet digestion procedure. The extractions were analysed by microwave plasma atomic emission spectroscopy. The breaking strength of the mosquito nets was measured using a tensile tester.

Results
The polypropylene mosquito net metal content was comparable to or less than the metal contents found in commercial surgical meshes and textile fibers.1 The polyester and polyethylene mosquito net metal contents were higher yet below toxic thresholds. The structural integrity of the nets was not compromised by autoclave sterilization.

Conclusions
The metal content of mosquito nets is below toxic thresholds and is comparable to a commercially available surgical mesh. The variability in metal contents found among the mosquito nets is likely due to the manufacturing process. However, there is no evidence that their metal contents are grounds for disqualification as an alternative to commercial surgical mesh.

Keywords: hernia repair, surgical mesh, mosquito net, metal content, tearing force

Introduction

A hernia is a protrusion of tissue or organs through the wall in which it is meant to be contained.[2] Hernia repair is usually a relatively simple procedure and is one of the most common surgeries performed worldwide.[3] Alloplastic meshes are the preferred treatment in hernia surgery because they mimic and reinforce authentic fascia and tendon.[2] Specifically, lightweight meshes with large pores are preferable because they decrease the risk of bacterial infection.[4]

Though alloplastic meshes represent the gold standard for hernia repair in developed countries, they remain underutilized in developing countries because of resource constraints.[5,6] Patients in developing countries, therefore, suffer from a higher incidence of severe consequences and mortality from untreated hernias; those who are able and willing to pay for surgery are severely burdened financially.[7] Moreover, high rates of untreated hernias hinder the economic progress of developing countries because affected individuals cannot work.[8] In an effort to provide practical care to these patients, several studies have evaluated the potential use of locally available and low-cost materials for hernia repair in these countries.[5,9-10] In this article, alloplastic meshes will be referred to as commercial surgical mesh. The low-cost meshes are pesticide free (untreated) mosquito nets that are employed to repair hernias in situations where the alloplastic mesh is neither financially affordable nor practically available.

While commercial alloplastic hernia meshes range in cost from $40 to hundreds of dollars, mosquito nets are ubiquitous and affordable, costing less than $20 per net. A single mosquito net could be sufficient for about 1600 hernia repairs. Thus, the use of a mosquito net for hernia repair is about 3700 to 4000 times less expensive than commercial meshes.[11] It has been calculated that the price of the area of mosquito net required to repair a typical hernia is less than one cent.[8] Therefore, hernia repair using local anaesthesia and mosquito net mesh is cost-effective in developing countries where medical resources are scarce, as was confirmed by studies conducted in Ecuador (2012),[9] India (2013),[10] and Uganda (2016).[12] The application of mosquito net mesh to hernia repairs represents an innovative way to treat hernias in vulnerable populations because mosquito nets share many structural similarities with commercial surgical mesh.[13] Kingsnorth et al.[11] observed that a commercially available surgical mesh and a mosquito net mesh appeared to be visually identical under the microscope. Additionally, multiple studies have shown that recurrence rates of hernia repairs using mosquito nets are comparable to those with commercially available surgical mesh and that clinical outcomes between the 2 materials do not differ significantly.[8,12,14-17] While these studies support the safety and long-term effectiveness of mosquito net meshes, more randomized trials are needed to confirm these results.[12,16]

One of the concerns regarding the use of mosquito nets is that of the biocompatibility of mosquito nets with the human body. For example, a study on rats concluded that mosquito nets made from a copolymer of polypropylene and polyethylene resulted in a significantly greater inflammatory response than with commercial mesh.[17] Additionally, Wilhelm et al.[18] observed that nylon mosquito nets were inferior to commercial polypropylene mesh in terms of material strength and inflammatory response. However, this same study also noted that all wounds healed without complications using both the commercial polypropylene mesh and the nylon mosquito net.[18] There is not a published consensus about the minimal required strength for prosthetic mesh used in hernia repairs. Zhu et al.[19] state that most synthetic meshes are strong enough for hernia repair, though they may differ among each other in material properties. Mosquito nets are made from various materials, such as nylon, polypropylene, polyester, and polyethylene, which differ in their physical, chemical, and mechanical properties.[8] For this reason, multiple types of mosquito nets were examined in this study.

A toxicological concern involves the presence of heavy metals in the mosquito nets themselves. This is particularly relevant when it comes to using mosquito nets in hernia repair because the patient faces life-long exposure to a textile material that may contain trace metals that are detrimental to human health. Heavy metal exposure is known to result in a variety of negative health effects, including metabolic derangements, organ damage, heart disease, nervous system disorders, and tumour development.[20]

The Oeko-Tex Standard 100 contains a set of limiting concentrations of heavy metals in textile products; textiles that receive this standard must be proven to have metal contents below the established limits.[1] However, this standard applies specifically to textiles used solely for external purposes, such as clothing. For this study, therefore, the mosquito nets were primarily examined to determine whether their heavy metal concentrations were comparable to, or greater than, that of commercial surgical mesh.

There are a variety of methods available for determining the metal contents in a textile material. Anodic stripping voltammetry, spectrophotometry, atomic absorption spectrometry, inductively coupled plasma optical emission spectrometry, inductively coupled plasma-mass spectrometry, and x-ray fluorescence spectrometry are all proposed methods for determining the amount of heavy metals in textile fabrics.[1] We chose to use the microwave plasma-atomic emission spectroscopy method to measure the extractable heavy metal contents in the mosquito net and commercial mesh materials. The extraction of the mesh samples was carried out using a wet digestion procedure as has been reported elsewhere.[1]

A final concern regarding the use of mosquito nets in hernia repair is the material's ability to maintain its structural integrity when subjected to sterilization and tension. Commercial surgical meshes are usually composed of polyester or polypropylene because these materials are relatively resistant to heat, which permits autoclave sterilization.[21] However, conflicting results exist concerning the ability of mosquito nets to withstand autoclave sterilization. In most developing countries, autoclave sterilization is the only practical sterilization method available. Several studies have confirmed that the material and mechanical properties of mosquito nets maintain their integrity after autoclave sterilization for 15 to 20 minutes at 121°C.[13,22] However, certain types of mosquito nets, such as linear low-density polyethylene (LLDPE) nets, possess melting points that are below the temperatures achieved during high-pressure autoclave sterilization and, thus, melt during this process.[11] On the other hand, inadequate sterilization leads to dire consequences from infection.

The abdominal wall twists and turns during most body movements, and any prosthesis must withstand any tension caused by movements including straining, lifting, and coughing. Therefore, it is essential that the mosquito net material be able to preserve its structural integrity to function as an effective hernia mesh. A recent study reported that there were not many significant differences between the tensile strength of various commercial surgical meshes and a polyethylene mosquito net.[13] Another study concluded that the tensile strength of an LDPE mosquito net mesh increased nearly 2-fold after it was sterilized at 121°C for 15 minutes.[8] Therefore, another goal of this study was to analyse the effects of autoclave sterilization on the tearing strength of different types of mosquito net materials.

Methods

Polymer structure

The structure of each mosquito net sample was examined using infrared spectroscopy. A Thermo Scientific Nicolet iS5 FTIR Spectrometer (Thermo Fisher Scientific, Waltham, MA, USA) with an iD7 ATR accessory was used with a diamond attenuated total reflection compression cell. OMNIC v9 (Thermo Fisher Scientific) software was used for spec-

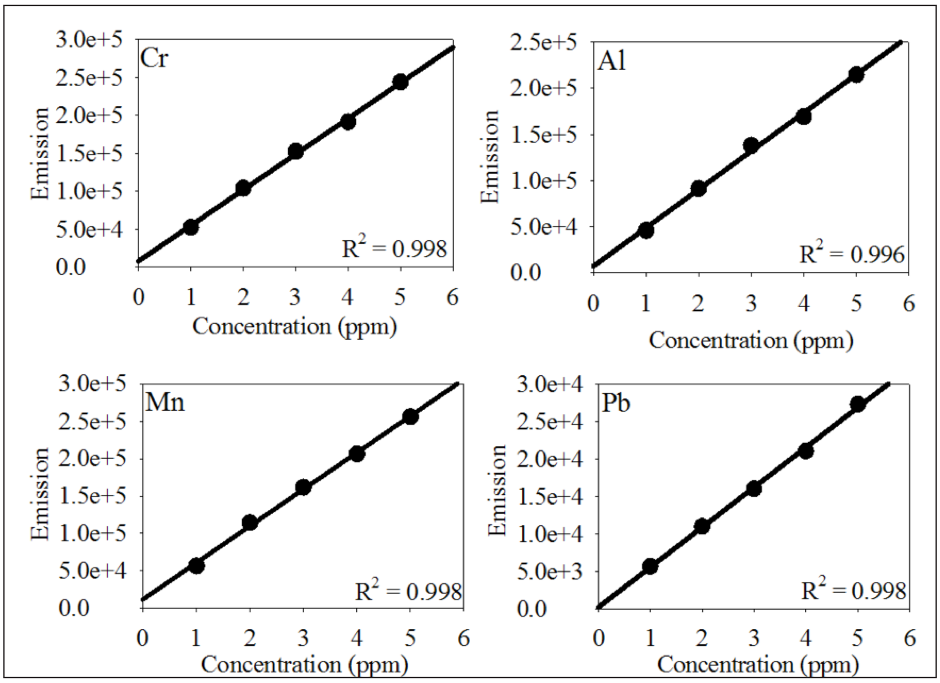

Figure 1. Calibration curves obtained for Cr, Al, Mn, and Pb (ppm) in a certified reference material sample

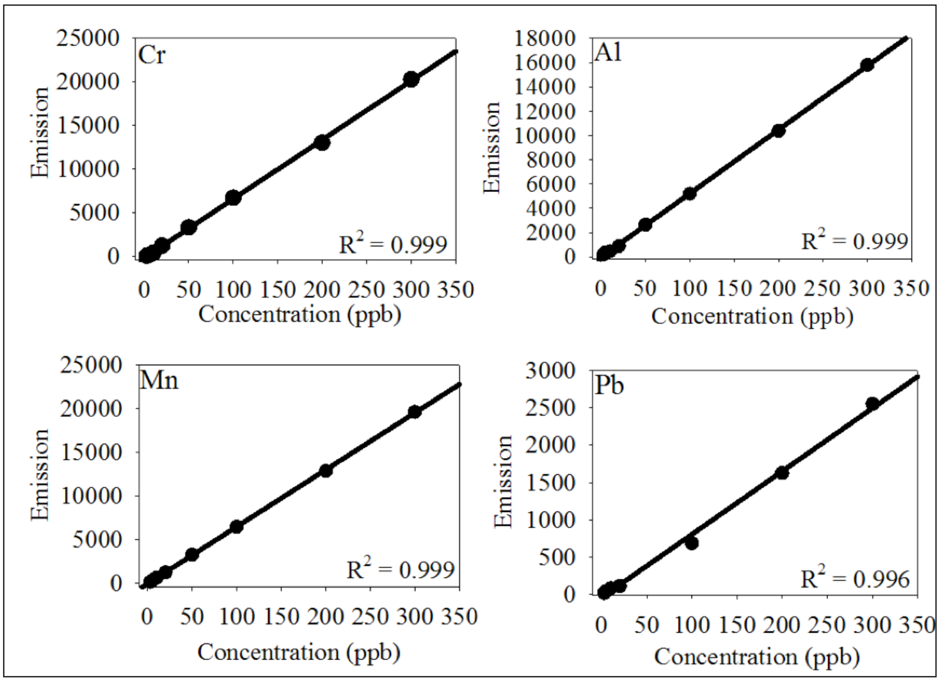

Figure 2. Calibration cCurves obtained for Cr, Al, Mn, and Pb (ppb) in a certified reference material sample

tral data analysis. Fourier-transform infrared spectroscopy (FTIR) analysis was conducted using the following conditions: 16 scans at a resolution of 4 cm^{-1}, scanned within the mid-infrared range 4000 to 400 cm^{-1}. Each spectrum was background-corrected.

Reagents and standards

A commercially purchased multielement wavecal solution (Agilent Technologies, Santa Clara, CA, USA) was used to ensure accurate microwave plasma atomic emission spectroscopy (MP-AES) measurements. All standard solutions

Table 1. Correlation coefficients, limits of detection, and limits of quantification of heavy metals in a certified reference sample

Heavy metals	Correlation coefficient (R^2)	LOD ($\mu g \cdot L^{-1}$)	LOQ ($\mu g \cdot L^{-1}$)
Zn	0.999	8.7	28.9
Cd	0.997	13.0	43.5
Ni	1.000	1.0	3.4
Pb	0.998	5.2	17.2
Cu	0.998	1.1	3.6
Co	0.996	1.8	5.9
Tl	0.999	1.6	5.2
Mn	0.999	0.8	2.5
Cr	0.999	0.1	0.5
Al	0.999	1.1	3.6
Mg	0.999	0.4	1.4
Fe	0.998	21.5	71.6

LOD = limit of detection; LOQ = limit of quantification

were made from stock solutions purchased from Agilent Technologies. All chemicals used in sample preparation were reagent-grade. For the wet digestion, trace-metal-free-grade nitric acid (70% HNO_3 from Fisher Scientific, Hampton, NH, USA) and hydrogen peroxide (30% H_2O_2 from Sigma-Aldrich, St. Louis, MO, USA) were used. Nanopure (NP) water (18.2 MΩ·cm resistivity) was obtained from a Barnstead water purifier (Fisher Scientific).

Collection of mesh samples

We used Prolene (Ethicon, Somerville, NJ, USA) polypropylene surgical mesh as the commercial mesh sample. The mosquito net samples consisted of nets made of low-density polypropylene (manufacturing site unknown), polyester (manufactured in Uganda, China, and Sri Lanka), and polyethylene (1 manufactured in India and 1 of unknown manufacturing origin that was packaged in Denmark). The mosquito nets from which the samples were taken were all either being used in, or considered for, hernia surgery.

Sample preparation

The mesh samples were cut, dried for 48 hours at 60°C, and the weighed. The concentrated HNO_3 used in the wet digestion procedures was trace-metal-free grade. The sample was heated in a 4:1 HNO_3 (70%)/H_2O_2 (30%) solution for 1 hour at 100°C to 110°C. The solution was cooled and transferred to a 25 mL volumetric flask and diluted with NP water to the mark. A control solution was prepared to account for any metal content in the HNO_3/H_2O_2 solution.

To analyse the dye on 1 of the polyester mosquito nets, a piece of the polyester net was cut then dried for 48 hours at 60°C. It was then soaked in a 4:1 HNO_3 (70%)/H_2O_2 (30%) solution for 1 hour to extract the dye into the solution. The solution was then transferred to a 25 mL volumetric flask and diluted with NP water to the mark.

MP-AES analysis

MP-AES analyses were performed on an Agilent 4200 instrument (Agilent Technologies). Background signals were subtracted from the analytical signals using Agilent MP Expert software. A blank solution was analysed to create a background spectrum, which was recorded and automatically subtracted from the standard and sample solution analyses.[1] The blank procedure was repeated for every experiment. The software was also used to optimize nebulization pressure and the viewing position for each wavelength selected to maximize sensitivity.[1] The MP-AES conditions used were as follows: (1) nebulizer: OneNeb; (2) spray chamber: double pass glass cyclonic; (3) read time: 5 seconds; (4) stabilization time: 15 seconds; (5) number of replicates: 3; (6) optical system: Czerny-Turner design monochromator with 600 mm focal length and fixed entrance slit; (7) detector: back-thinned solid state CCD detector (532 × 128 pixels); (8) analytes (wavelengths): Al (396.15 nm), Cr (425.43 nm), Cu (324.75 nm), Mn (403.08 nm), Ni (352.45 nm), Pb (405.78 nm and 283.31 nm), Zn (213.86 nm), Co (340.51 nm), Cd (228.80 nm), Tl (535.05 nm), Fe (259.94 nm), and Mg (279.55 nm).[1]

Table 2. Heavy metal contents (μg/g) of a commercial mesh and mosquito nets after wet digestion (mean of 3 replicates ± standard deviation)

Metals	Commercial surgical polypropylene mesh (Prolene, Ethicon) (μg/g)	Polypropylene mosquito net (manufacturer unknown) (μg/g)	Polyester mosquito net (manufactured in Sri Lanka) (μg/g)	Polyethylene mosquito net (manufactured in India) (μg/g)
Cu	nd	nd	nd	nd
Pb	nd	nd	nd	nd
Fe	2.91 ± 0.41	nd	27.90 ± 0.60	2.68 ± 0.54
Mg	0.22 ± 0.02	0.85 ± 0.04	5.79 ± 0.04	4.48 ± 0.04
Mn	nd	nd	0.31 ± 0.01	0.08 ± 0.01
Cr	nd	nd	0.15 ± 0.01	0.04 ± 0.01
Al	0.49 ± 0.04	2.14 ± 0.07	16.38 ± 0.12	4.14 ± 0.09
Zn	nd	1.42 ± 0.13	69.48 ± 0.29	1.65 ± 0.19
Cd	nd	nd	nd	nd
Ni	nd	nd	0.27 ± 0.02	nd
Tl	nd	nd	nd	nd
Co	nd	nd	nd	nd

nd = not detected

Quality control

A fresh set of calibration standards was prepared for every mesh analysis to ensure accurate measurements. Two sets of calibration standards were prepared: 1 in the range of 1 to 5 mg/L using a multielement standard solution in 5% HNO_3 (Figure 1), and the second set in the 3 to 300 μg/L range (Figure 2).

Calibration curves for all metals analysed are included with the supplementary material (Figure S1). All calibration curves in the ppm and ppb range used in the data analysis consisted of a correlation coefficient greater than 0.99. Limits of detection (LOD) and limits of quantification (LOQ) were calculated by multiplying the standard deviation of 7 consecutive blank measurements by 3 and 10, respectively, and dividing by the slope of the calibration curve. The values obtained are summarized in Table 1.

Tearing force sample preparation

The tearing forces of the polypropylene mosquito net (manufacturing site unknown), polyester mosquito net (manufactured in China), and polyethylene net (packaged in Denmark, manufacturing site unknown) were measured according to 2 protocols: after autoclave sterilization at 121°C for 15 minutes and after receiving no prior treatment. For each protocol, 3 samples measuring 5.08 cm × 25.4 cm (2 in × 10 in) in the warp direction and 3 samples of the same size in the weft direction were cut. The warp direction was established as the direction of the longitudinal weave of the net, and the weft direction was perpendicular to the warp direction. Overall, 12 samples from each type of mosquito net were cut and tested. The tearing force of the commercial surgical mesh was not tested.

Tearing force test procedure[23,24]

Tearing force measurements were performed using a Starrett FMS500 Tensile Strength Tester (L. S. Starrett Company, Athol, MA, USA). The distance between the upper and lower clamps was set to 15.24 cm (6 in) for all mosquito nets that had not been autoclaved and the autoclaved polyester samples, 10.16 cm (4 in) for the autoclaved polypropylene net and the autoclaved polyethylene net in the warp direction, and 5.08 cm (2 in) for the autoclaved polyethylene net in the weft direction. Since autoclaving caused the polyethylene and polypropylene mosquito nets to shrink from their original cut-lengths, the distance between the clamps had to be decreased from 15.24 cm (6 in) accordingly. However, the autoclaved polyester mosquito net did not shrink, so the clamps were kept at the same initial distance as the nonautoclaved mesh. The mosquito nets were pulled apart at a rate of 12.7 cm/minute (5 in/minute), and the maximum force at which the mosquito net tore was recorded for each sample. The results from the samples were averaged to obtain the warp tearing force, the weft tearing force, and the % elongation of each type of mesh with and without autoclave sterilization.

Table 3. Heavy metal content (µg/g) of polyester mosquito net dye

Metals	Polyester mosquito net* (µg/g)	Polyester mosquito net dye (µg/g)
Cu	nd	nd
Pb	1.39 ± 0.43†	nd
Fe	4.73 ± 0.35	nd
Mg	12.25 ± 0.45	9.95 ± 0.12
Mn	0.24 ± 0.01	nd
Cr	0.28 ± 0.04	nd
Al	15.54 ± 0.14	0.31 ± 0.09
Zn	37.52 ± 0.87	0.72 ± 0.11
Cd	nd	nd
Ni	nd	nd
Tl	nd	nd
Co	nd	nd

nd = not detected; *manufactured in China; †R2 = 0.9818

Table 4. Tearing force and percent elongation of mosquito nets (polypropylene, polyester, and polyethylene) with and without autoclave sterilization (mean of 3 replicates ± standard deviation)

Mosquito net	Tearing force (N)		% Elongation	
	Control	Autoclave sterilization	Control	Autoclave sterilization
PP warp	72.1 ± 17.3	92.5 ± 7.6	39 ± 6	81 ± 18*
PP weft	42.3 ± 4.0	72.5 ± 3.7*	77 ± 7	102 ± 19
PES warp	71.6 ± 4.8	73.8 ± 7.1	32 ± 3	33 ± 2
PES weft	39.6 ± 6.7	45.4 ± 2.7	74 ± 5	74 ± 4
PE warp	153.5 ± 8.5	258.0 ± 15.6*	51 ± 3	161 ± 5*
PE weft	79.2 ± 12.9	115.7 ± 9.3*a	96 ± 5	353 ± 66*
Co	nd	nd	nd	nd

*Statistically significant at $P < 0.05$; [a]mean of 2 replicates ± standard deviation; PP = polypropylene mosquito net of unknown manufacturing origin; PES = polyester mosquito net manufactured in China; PE = polyethylene mosquito net of unknown manufacturing origin, packaged in Denmark

Results

Heavy metal content analysis

Calibration curves

MP-AES is an alternative method for quantifying metal content and is comparable to graphite furnace atomic absorption spectroscopy (GFAAS) and inductively coupled plasma optical emission spectroscopy (ICP-OES). A recent study[1] using MP-AES for textiles showed limits of detection and limits of quantitation in the ppm range, but as shown in Table 1, we report both in the low ppb range. These results are consistent with those reported by the instrument manufacturer for various analyses.[25]

Polymer structure

The infrared spectra of the commercial polypropylene surgical mesh, the polypropylene mosquito nets, the polyester mosquito nets, and the polyethylene mosquito nets were taken and compared to reference spectra. The spectrum of each sample closely matched the available reference spectra of the polymer in question as well as the spectra of other mosquito net samples of the same chemical make-up. All spectra are included with the supplementary materials (Figure S2 and Figure S3).

The heavy metal constituents for the commercial surgical mesh and the mosquito nets are summarized in Table 2. Multiple specimens of the commercial mesh and the mos-

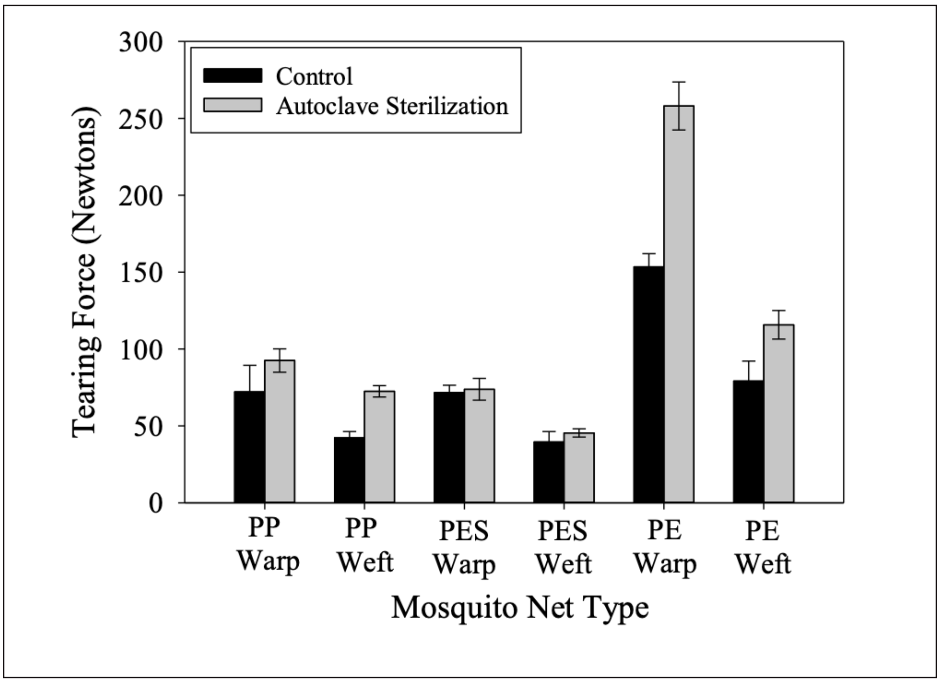

Figure 3. The effect of autoclave sterilization on tearing force (N) of polypropylene, polyester, and polyethylene mosquito nets in the warp and weft directions

PP = polypropylene mosquito net of unknown manufacturing origin; PES = polyester mosquito net manufactured in China; PE = polyethylene mosquito net of unknown manufacturing origin, packaged in Denmark

quito nets were analysed; the data corresponding to each individual specimen are provided for reference with the supplemental materials (Tables S1-S4).

The heavy metal content of the mosquito nets was comparable to that of the commercial surgical mesh. Among the low-cost nets in Table 2, the polypropylene mosquito net had the lowest heavy metal concentrations. The polyester and polyethylene mosquito nets both had higher heavy metal concentrations than the polypropylene mosquito net and the commercial surgical mesh. Overall, the polyester mosquito net had the highest concentrations of heavy metals, particularly iron, aluminium, and zinc. Additionally, the polyester mosquito net had the highest variability among individual specimens. Neither copper, lead, cadmium, thallium, nor cobalt were found in any of the specimens listed in Table 2.

According to the Oeko-Tex Standards of heavy metal limits in textiles, both the commercial surgical mesh and the mosquito nets had heavy metal concentrations that were below the specified limits.[1] The polypropylene and polyester mosquito nets (Table 2) had lower heavy metal concentrations than the polypropylene and polyester textile fibres analysed by Sungur and Gülmez in all cases except for zinc—which was not detected in the textiles—and magnesium, the concentration of which was not reported.[1] Data for the heavy metal content of polyethylene textile fibers were not available for comparison with the polyethylene mosquito net used in our study.[1]

Of the mosquito net samples, the polypropylene net contained the lowest heavy concentrations. Iron was not detected in the polypropylene mosquito net, while it was detected in the high-cost commercial mesh (2.91 ± 0.41 µg/g). The polypropylene mosquito, however, contained higher amounts of zinc (1.42 ± 0.13 µg/g), magnesium (0.85 ± 0.04 µg/g) and aluminium (2.14 ± 0.07 µg/g) than the high-cost commercial mesh.

The polyester mosquito net contained higher amounts of iron (27.90 ± 0.60 µg/g), magnesium (5.79 ± 0.04 µg/g), manganese (0.31 ± 0.01 µg/g), chromium (0.15 ± 0.01 µg/g), aluminium (16.38 ± 0.12 µg/g), zinc (69.48 ± 0.29 µg/g), and nickel (0.27 ± 0.02 µg/g) than the high-cost commercial mesh.

The polyethylene mosquito net had more magnesium (4.48 ± 0.04 µg/g), manganese (0.08 ± 0.01 µg/g), chromium (0.04 ± 0.01 µg/g), aluminium (4.14 ± 0.09 µg/g), and zinc (1.65 ± 0.19 µg/g) than the commercial surgical mesh. The polyethylene mosquito net had less iron than the high-cost commercial mesh.

Additionally, the metal content of the dye from 1 of the polyester mosquito nets was analysed because it was observed that the dye leached into and coloured the wet digestion solution. The metal content of the dye was compared with the metal content of the polyester mosquito net itself (Table 3). The dye had minimal amounts of most of the metals. However, the dye in the polyester mosquito net contained a high concentration of magnesium (9.95 ± 0.12 µg/g) relative to that of the net (12.25 ± 0.45 µg/g), suggesting that the dye contributed to the majority of the magnesium detected in the polyester mosquito net.

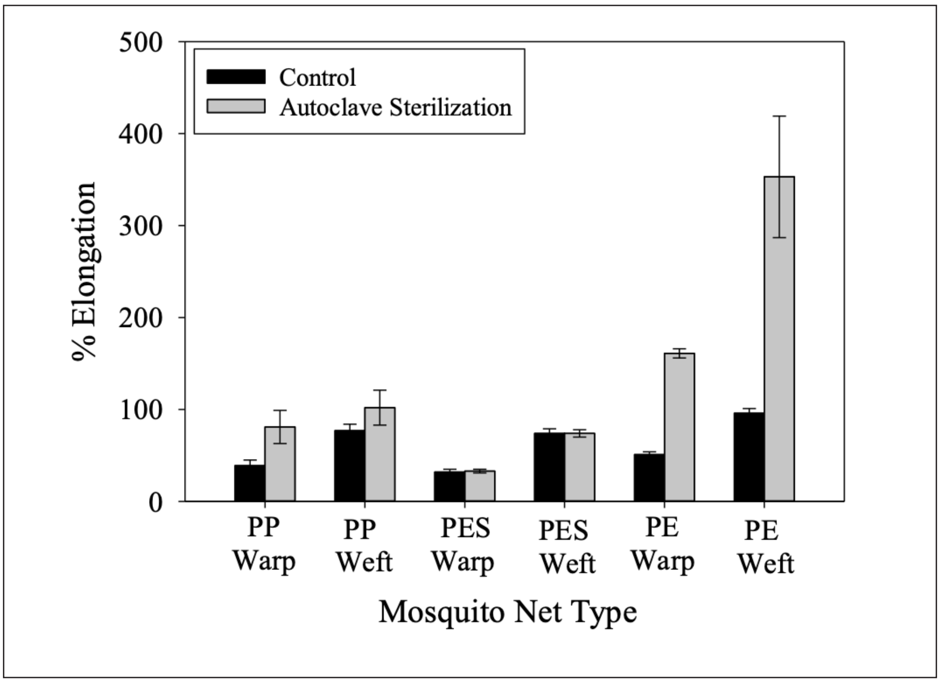

Figure 4. The effect of autoclave sterilization on the % elongation of polypropylene, polyester, and polyethylene mosquito nets

PP = polypropylene mosquito net of unknown manufacturing origin; PES = polyester mosquito net manufactured in China; PE = polyethylene mosquito net of unknown manufacturing origin, packaged in Denmark

Tearing force analysis

Of the 3 types of mosquito nets investigated, only the polyethylene mosquito net shrank after undergoing autoclave sterilization. The original samples, which were 5.08 cm × 25.4 cm (2 in × 10 in), shrank to approximately 1.901 cm x 12.7 cm (0.75 in × 5 in). This represents an 81% reduction in size. Neither the polypropylene nor the polyester mosquito nets shrank after autoclave sterilization; photographs comparing the samples are included with the supplemental material (Figure S4).

When comparing the mosquito net tearing forces, we observed that autoclave sterilization of the nets did not compromise their structural integrity. A two-sample t-test assuming unequal variances revealed that autoclave sterilization significantly increased the tearing forces of all of the mosquito nets except for the polypropylene mosquito net in the warp direction and the polyester mosquito net in both directions (Table 4). After autoclave sterilization, the mean tearing force of the polypropylene mosquito net material in the weft direction increased from 42.3 ± 4.0 N to 72.5 ± 3.7 N. The mean tearing force of the polyethylene mosquito nets increased from 153.5 ± 8.5 N to 258.0 ± 15.6 N in the warp direction, and 79.2 ± 12.9 N to 115.7 ± 9.3 N in the weft direction. There was no statistically significant change in the tearing force of the polyester mosquito net material in the warp direction (71.6 ± 4.8 N to 73.8 ± 7.1 N after autoclave sterilization) or the weft direction (39.6 ± 6.7 N to 45.4 ± 2.7 N after autoclave sterilization), or polypropylene in the warp direction (72.1 ± 17.3 N to 92.5 ± 7.6 N). For each mosquito net, the warp direction had a higher tearing force than the weft direction (Figure 3).

Percent elongation was defined as the ratio between the maximum length that the mosquito net samples reached before breaking and their initial length. The percent elongation values of the mosquito nets with and without autoclave sterilization are shown in Table 4. Autoclave sterilization significantly increased the percent elongation of polyethylene in the warp (51 ± 3 % to 161 ± 5 % after sterilization) and weft (96 ± 5 % to 353 ± 66% after sterilization) directions, as well as polypropylene in the warp direction (39 ± 6 % to 81 ± 18 % after sterilization). There was no statistically significant change in the percent elongation for the polyester samples in either the warp or weft directions, or for polypropylene in the weft direction (Figure 4).

Discussion

Various studies have already concluded that the use of mosquito nets for hernia repair produces acceptable clinical results and does not lead to adverse long-term outcomes .[8,12,14-17] Our results further support these conclusions in that the heavy metal contents observed in the mosquito net specimens were below the specified limits in other textile standards.[1] Moreover, the concentrations of the individual metal constituents of the mosquito nets were comparable to, or slightly higher than, those of a commercially available surgical mesh.

We note that the polypropylene mosquito net material had lower heavy metal concentrations than the polyester and polyethylene mosquito nets. Nonetheless, all 3 types of mosquito net had metal concentrations that do not appear to pose a health risk. We surmise that any variability of the metal concentrations in the different mosquito net types is likely due to the specific manufacturing environments of the individual nets. Based on our study, we recommend polypropylene and polyethylene mosquito nets as suitable for hernia repair surgery, while we caution against the use of polyester mosquito nets due to the wide variation of metal concentrations found in polyester nets of various origins. Moreover, 1 of the polyester nets also contained a dye coating that dissolved in an acidic environment. A future study of polypropylene and polyethylene mosquito nets from manufacturers around the world is recommended to determine if any broader patterns exist for different types of mosquito nets.

Contrary to our expectations, the breaking strengths of the mosquito nets were not compromised by autoclave sterilization; for the polyethylene and polypropylene mosquito nets in the weft direction, this process even appears to have reinforced the structural integrity of the nets. Moreover, the percent elongation results imply that the mosquito nets, especially the polyethylene and polypropylene nets, remain flexible despite autoclave sterilization. This flexibility enhances the nets' ability to incorporate seamlessly into the surrounding body tissue and is likely to reduce discomfort to patients. It is important to note that our study only compared within individual net types with and without autoclave sterilization. We did not compare different types of mosquito nets to each other in this study because the denier size, or fibre thickness, of many of the mosquito nets was unknown. Therefore, any comparisons of the tearing force of different mosquito net types would be confounded by denier size. A further study comparing the force required to break different mosquito nets of known denier size is highly recommended to address this limitation. We did observe that, of the mosquito nets that did report a denier size, a value equal to, or greater than, 100 shows similar flexibility to a commercial surgical mesh. Additionally, an investigation as to why autoclave sterilization increases the tearing strength of mosquito nets would be beneficial.

Clinical considerations

Mosquito nets vary widely in composition and manufacturing history. While the metal concentrations of the mosquito nets studied here were comparable with the commercial surgical mesh, a study of mosquito nets from other manufacturers may yield different results. Although the results of this study seem to favour the use of mosquito nets for hernia repair, clinicians who utilize this alternative material are cautioned to remain vigilant for hernia recurrence as well as any symptoms of heavy metal toxicity in their patients.

Conclusions

Clinicians should be made aware of the use of mosquito nets in hernia repair as an acceptable alternative treatment in resource-poor settings. Although the heavy metal concentrations of the mosquito nets in this study were comparable to those the commercial surgical mesh, and earlier studies have confirmed that mosquito nets are more cost-effective for areas with scarce medical resources,[8-12] physicians should remain wary of mosquito nets of unknown composition and manufacture, as they may contain substances that are incompatible with, or even toxic to, the human body. Further studies and comparisons of mosquito nets from different manufacturers are recommended to account for the variability among different mosquito nets.

As for the investigation of mosquito net tearing forces, a limitation of this study is that it only compared the tearing forces within individual net types, with and without autoclave sterilization. This was because the denier sizes were unknown for some of the samples, so a comparison across different types of mosquito nets was not possible. Further studies comparing the tearing forces of different types of mosquito nets of known denier size are recommended.

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