

Physical Durability of Two Types of Long-Lasting Insecticidal Nets (LLINs) Three Years after a Mass LLIN Distribution Campaign in Mozambique, 2008–2011

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Abstract. We conducted a prospective evaluation to measure the physical durability of two brands of long-lasting insecticidal nets (LLINs) distributed during a campaign in 2008 in Nampula Province, Mozambique. Households with LLINs tagged during the campaign (6,000) were geo-located (34%) and a random sample was selected for each of 3 years of follow-up. The LLINs were evaluated in the field and a laboratory for presence of holes and a proportional hole index (pHI) was calculated following the World Health Organization guidelines. We performed 567 interviews (79.0%) and found 75.3% (72.1–78.4%) of households retained at least one LLIN after 3 years; the most common cause of attrition was damage beyond repair (51.0%). Hole damage was evident after 1 year, and increased by year. Olyset had a significantly greater mean number of holes and pHI compared with PermaNet 2.0 brand (all P values ≤ 0.001). Additional information about LLIN durability is recommended to improve malaria control efforts.

INTRODUCTION

Insecticide-treated nets (ITNs) are known to be effective in reducing malaria morbidity and mortality by reducing malaria transmission.^{1–3} Long-lasting insecticidal nets (LLINs), through their ability to retain insecticide for years and therefore their effect on malaria transmission, are playing an important role in the ongoing malaria control scale-up in sub-Saharan Africa.⁴ Accordingly, enormous efforts are taking place in malaria-endemic areas of sub-Saharan Africa to achieve ownership of at least one ITN or LLIN per household. It is estimated that these efforts led to an increase in household ownership from 3% in 2000 to 53% in 2012⁴ mostly as a result of the mass distribution of LLINs. Wide-scale introduction of LLINs in sub-Saharan Africa started in the early to mid-2000s after the World Health Organization (WHO) Pesticide Evaluation Scheme (WHOPES) approval of the first LLIN products.⁵ Manufacturers developed LLINs in response to WHO's stimulus for a practical solution to treating bed nets by manual dipping, after evidence of their impact on childhood mortality was shown.⁶ An LLIN is defined as a factory-treated mosquito net expected to retain its biological activity for a minimum number of standard WHO washes and a minimum period of time under field conditions,⁷ expected to be 4 to 5 years.⁵ Despite the large investment in the procurement and distribution of ITNs and LLINs, which is estimated to have increased from 6 million US dollars (USD) in 2004 to 92 million in 2011,⁴ little information exists on the physical durability of LLINs in the field; and few malaria control programs to date have systematically monitored the performance of LLINs in terms of physical durability after mass distributions.^{8–16} Several studies provide evidence that the levels of insecticide present in LLINs months and years after their distribution remains adequate^{10,17–23}; however, this information alone does not entirely address whether LLINs remain effective as a vector

control tool over several years of daily use. The physical integrity of the LLIN, specifically the presence of holes, tears, and repairs, needs to be taken into account when determining whether an LLIN is capable of protecting individuals or communities from mosquitoes infected with malaria.^{8,12,17,23,24}

The recently drafted WHOPES guidelines²⁵ have the purpose of assisting malaria control programs in performing monitoring of the durability of LLINs. This document states that programs need information on LLIN durability to choose products that perform better in specific settings and to estimate rate of LLIN replacement. In this context, we conducted a prospective evaluation with the objective of monitoring the physical integrity of two different brands of LLINs in Nampula Province, Mozambique after a mass LLIN distribution campaign in 2008. The information obtained from this evaluation provides one of the first simultaneous evaluations of the physical durability of two brands of LLINs in the field over an extended 3-year time frame. These results can be used by the Mozambique National Malaria Control Program (NMCP) and add to the global evidence database, in determining when to replace LLINs distributed through mass campaigns based on the LLIN physical durability.

METHODS

In October 2008, as part of a national measles vaccination campaign, Nampula Province, Mozambique conducted a mass LLIN distribution campaign; this combined campaign will be referred to as the “LLIN distribution campaign.” Our prospective evaluation followed LLINs that were tagged at the time of the LLIN distribution campaign over 3 years and included measuring the physical integrity of the LLINs, the insecticidal activity as measured by WHO cone bioassay, and the insecticide retention as measured by high performance liquid chromatography and gas chromatography. Only the physical integrity of the LLINs is presented in this report.

Study area. Nampula Province is in northern Mozambique with a single rainy season from December to April. The population, mostly rural, is dependent on agriculture and fishing. Nampula Province is the most populous province in

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Mozambique with over 4 million people living in 21 districts. The Makua are the predominant ethnic group in this province (Figure 1). Malaria transmission in Nampula Province, as in all of Mozambique, is perennial with a seasonal peak that largely coincides with the rainy season. The prevalence of malaria, as measured by rapid diagnostic tests among children between the ages of 6 and 59 months in Nampula Province, was found to be 43.3% in the 2011 Demographic and Health Survey.²⁶

LLIN distribution, tagging, and mapping. Approximately 800,000 LLINs were distributed to all children < 5 years of age attending the LLIN distribution campaign sites, which were usually health centers. Roughly 80,000 LLINs were Olyset brand donated by the United Nations Children's Fund (UNICEF) and 720,000 LLINs were PermaNet 2.0 brand donated by the President's Malaria Initiative. For our prospective evaluation, we selected six LLIN distribution campaign sites to conduct the tagging of LLINs at the time of distribution for a prospective evaluation (Figure 1). These sites were selected for evaluation convenience, based on the ability to rapidly locate the tagged LLINs by coordinating with a provincial "hang-up/keep-up" campaign conducted by Mozambique Red Cross (MRC) volunteers in selected dis-

tricts in Nampula Province 1 month after the LLIN distribution campaign.

The survey team tagged 1,000 LLINs with a bar-coded label during the LLIN distribution campaign at each of the six selected sites, for a total of 6,000 tagged LLINs (2,000 were Olyset brand (polyethylene fibers, 150 Denier, Tulle [3.5.52]) and 4,000 were PermaNet 2.0 brand (polyester material, 100 Denier, Traverse net [3.5.50])). These tagged LLINs were randomly distributed to eligible children attending the LLIN distribution campaign, and recipients of these LLINs were not informed about the tagged status of their LLINs. Except for the barcode tag added to the LLIN, no other difference existed between tagged and non-tagged LLINs. The MRC volunteers identified households with beneficiaries of the LLIN distribution campaign either through their own knowledge of the community or through community informants: all households with young children were targeted for the hang-up/keep-up household visits. The MRC volunteers identified and registered tagged LLINs when conducting the household visits for the "hang-up/keep-up" campaign. The MRC volunteers then shared the locations of households they identified as owning a tagged LLIN with an evaluation team that

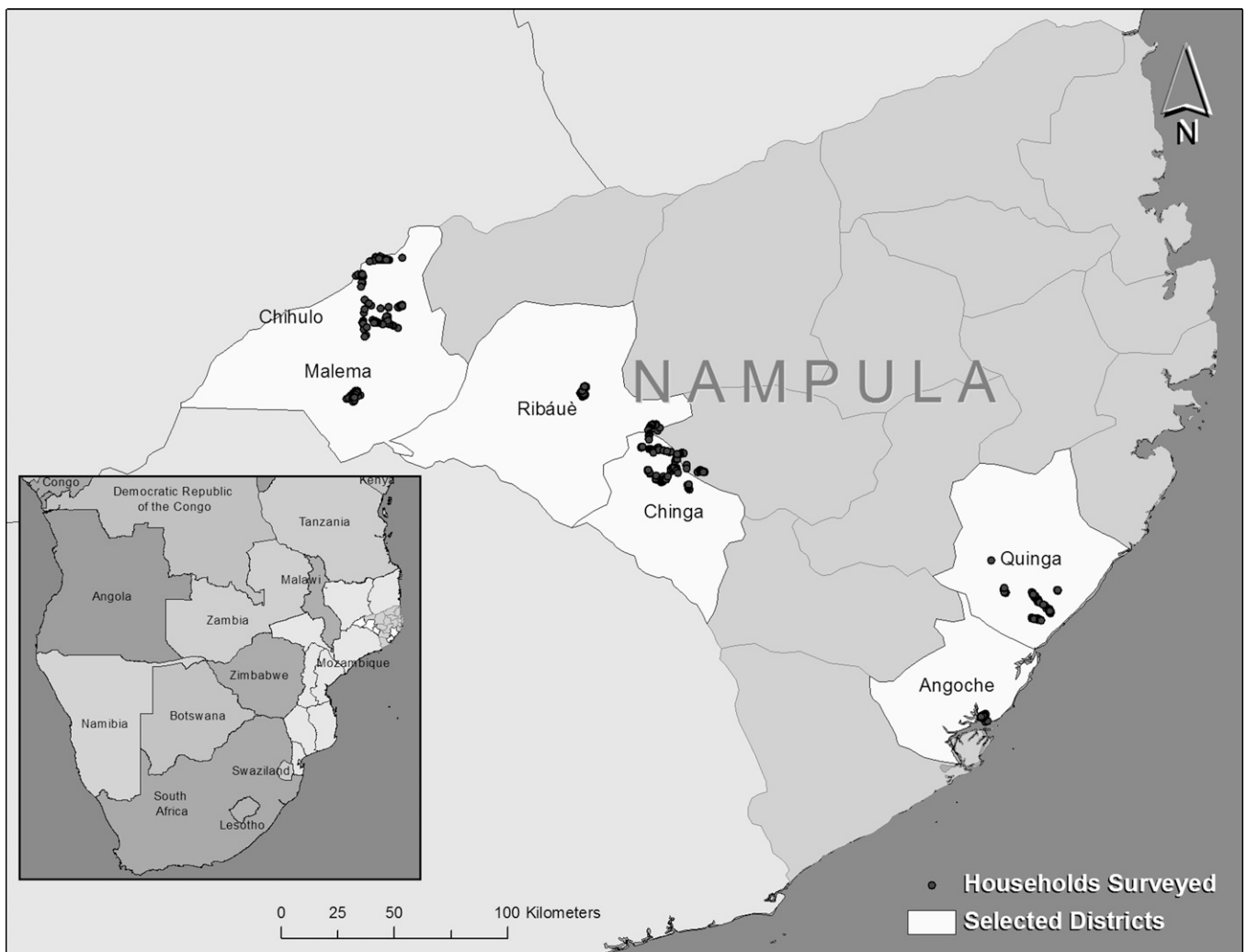


FIGURE 1. Map of study area in Nampula Province, Mozambique. White areas represent selected districts and black dots represent locations where households were surveyed and bed nets collected for physical durability assessments.

returned 1 or 2 days after the hang-up campaign to map the household using personal digital assistants (PDA, SoMo 655, SocketMobile, Newark, CA) with global positioning system units (GPS, USGlobalSat GPS, SiRF STAR III, Chino, CA).

Sample design for household selection. The sampling frame consisted of the list of the GPS coordinates of each household known to have at least one tagged LLIN. We randomly selected the households (without replacement) from the list of GPS coordinates for each year of follow-up for each LLIN distribution site.

The sampling design was based on detecting differences in insecticidal levels because this is a component of the evaluation and information on attrition rates was not available. The WHO guidelines²⁵ recommend a sampling of 30 LLINs per site per year; assuming a power of 90%, $\alpha = 0.05$, and standard deviation = 5, this design will be able to detect at least a 5.6% reduction (from a baseline of 55 mg/m²) in the insecticide level in each site. Therefore, to sample an expected number of 30 households each year, adjusted for non-response, three lists of households were randomly generated with 35, 40, and 45 households from each of the six sites for years 1, 2, and 3, respectively, for a total of 210, 240, and 270 households to be sampled. Only one tagged LLIN was randomly selected from the tagged LLINs in use in each household, if a household had more than one tagged LLIN.

Follow-up surveys. We conducted annual follow-up surveys in either October or November of 2009, 2010, and 2011. The evaluation teams visited the randomly selected households with the aid of the GPS navigation; and conducted an interview of a competent family member using a standardized questionnaire on the PDA. If the household was closed or no competent respondent was present at the time of the first visit, the house was visited again at a different time of day or the next day, for up to three attempts to collect data from the household. Verbal consent was obtained before the interview was carried out. The evaluation team member conducting the interview determined if the household still possessed a tagged LLIN from the 2008 campaign. If no tagged LLIN was present, the interviewer inquired about the fate of the LLIN (e.g., lost, stolen, destroyed, abandoned, etc.).

The survey team conducted an LLIN inspection in the field and counted the number of holes of various sizes either manually (size of a finger, fist, or head, during follow-up surveys conducted in years 2009 and 2010) or using a cone with markings at known diameters for hole size (20, 50, 80, and 100 mm, in follow-up year 2011). After the interview and LLIN inspection was completed, the LLINs were individually labeled with the date and collection site code and placed in opaque plastic bags (to protect them from light). A new LLIN was given to the household as a replacement for the LLIN taken. The collected LLINs were transported to the laboratory at the National Institutes of Health (Instituto Nacional de Saúde, INS), in Maputo for a more rigorous LLIN inspection, hole counting, and residual insecticide testing.

LLIN inspection in the laboratory. We constructed cube-shaped frames of ~180 cm at the INS using commercial polyvinyl chloride (PVC) pipe and fittings and hung black plastic sheeting from the top rail to provide a contrasting background to facilitate the examination of the LLINs. The LLINs were removed from the plastic bags and carefully draped over the frame to avoid tears from placing the net over the frame (Figure 2). We assessed the physical integrity of the LLIN by



FIGURE 2. Example of collected used net over cube-shaped frame for hole counting and measurements in the laboratory.

looking for the presence of holes, by measuring the size (mm) and position (distance from the bottom of the net) of each hole and recording the measurements and the presence of repairs into a PDA. Because it was noted during the LLIN inspection that holes tended to be elliptical in shape, holes were measured along the major axis in the follow-up years 2009 and 2010 and by both their major and minor axes in follow-up year 2011. Holes that were smaller than 0.5 cm in size were not counted in follow-up years 2009 or 2010 but were included in a separate category in the follow-up year 2011. Holes located on side panels of the LLIN also had the vertical distance from the bottom edge of the net to the center of the hole measured. The holes on the LLIN roof panel and the condition of the seams were also measured. Burns and repairs (knots, patches, and stitches) were recorded: in the case of sewn repairs, the length of stitching and location from the bottom edge of the net to the center of the repair was estimated and recorded.

Hole categorization. We used the diameter of each hole as measured in the field with the marked cones or measured in the laboratory to categorize the holes, based on the recently published WHOPES guidelines.²⁵ For holes measured in the field using the manual method, those considered to be smaller than a thumb in diameter were classified as measuring between 0.5 and 2 cm (hole size category 1); holes larger than a thumb but smaller than a fist were between 2 and 10 cm (hole size category 2); holes larger than a fist but smaller than a head were between 10 and 25 cm (hole size category 3); and holes larger than a head were classified as measuring more than 25 cm (hole size category 4). Holes smaller than 0.5 cm were not included in this analysis.

Data management and statistical analysis. We calculated a PHI for each net using the WHOPES guidelines in an attempt to provide an estimate of relative net damage. As an improvement over just summing the total number of holes per net, this index uses a weighted sum of the holes per net to account for the likelihood that a mosquito could penetrate a hole in an LLIN based on the size of the hole. The index weights are

based on the estimated area of each hole category (calculated using the radius of the mid-point of a category) and correspond to 1, 23, 196, and 578 for the four respective categories mentioned previously. The net PHI was calculated by multiplying the number of holes in each category by the corresponding weight and summing this across categories.

Wealth status was calculated using a principal-components analysis based on economic characteristics and possession of assets using questions modeled after the Demographic Health Survey.²⁷ The assets used in these calculations included: type of window, floor, and toilet; source of drinking water and cooking fuel; and presence of household assets such as electricity, radio, TV, phone, refrigerator, bicycle, and car. A wealth index was created from the first principle component for each household, which was then categorized into a wealth quintile.

During the field evaluation and measuring of holes in the laboratory, data were entered directly into PDAs (Dell Axim X51, Round Rock, TX) using questionnaires developed with Visual CE (Syware, Inc., Cambridge, MA) software. Data were downloaded directly into the MS Access database (Redmond, WA). Data cleaning and analyses were performed using SAS survey procedures (e.g., SurveyFreq, SurveyLogistic and SurveyReg, version 9.32, SAS Institute, Cary, NC). Analyses were performed separately for each year and were stratified by district and LLIN type where appropriate. Standard errors of estimates were adjusted for stratification and non-response when appropriate (i.e., household data estimate when no net was found) using SAS survey procedures.

Ethical approval. Approval for this study was obtained from the Bioethical Committee of the Ministry of Health, Mozambique (Maputo, Mozambique). The Centers for Disease Control and Prevention (CDC) Institutional Review Board (IRB) approved the study as a routine public health evaluation that did not require CDC IRB review.

RESULTS

Interviews. We located 2,023 of the 6,000 (33.7%) tagged LLINs among 1,549 households during the household visits of the “hang-up/keep-up” campaign, and we randomly selected 210, 240, and 270 households for interviews in years 1, 2, and 3 of follow-up among these 1,549 households, respectively. Table 1 presents the results of the outcome of the interviews conducted; 567 interviews were conducted, out of the 720 expected interviews (79%). The most common cause (51%) of loss of follow-up across the 3 years was the household moved away and this was similar for the six distribution sites (data not shown).

The map in Figure 1 shows the locations of the households, in or around six villages, selected for follow-up. Two villages are located on the Indian Ocean coast, with 34% of the house-

holds (Quinga and Angoche); the remaining four are inland (66% of the households). Three of the localities, where 50.4% of the households are located, are remote villages; the population survives on subsistence farming and has little access to amenities (Chihulo, Chinga, and Quinga). The remaining three localities, where 49.6% of the households are located, are small villages with basic infrastructure such as running water, electricity, and markets (Ribaue, Angoche, and Malema). The three remote villages have the highest proportions of households that belong to the lower quintiles, whereas the small villages had households with higher wealth quintiles. The nets brands were evenly distributed among the households in different wealth quintiles.

LLIN attrition. We excluded six of the 567 households interviewed over the 3 years of follow-up because they reported not having received an LLIN during the 2008 campaign. Among the 561 households reporting having received an LLIN in 2008, 83.4% (95% confidence interval [CI]: 80.1–87.4%) had retained at least one. Overall, 374 (66.7% [95% CI: 62.6–70.6%]) retained all of the LLINs they received during the campaign, 93 (16.6% [95% CI: 13.6–19.9%]) did not retain any, and 94 (16.5% [95% CI: 13.8–20.1%]) retained only some of the LLINs received in 2008. The most common causes of LLIN attrition reported among the 156 households that did not retain all of their nets were that they were damaged beyond repair (51.0% [95% CI: 42.8–59.1%]) or given away (23.5% [95% CI: 17.1–31.1%]). However, in the first and second years of follow-up, the most common causes of LLIN attrition were having given the LLIN away or having it stolen. Only 5.0% (95% CI: 0.1–24.9%) in the first year and 34.7% (95% CI: 21.7–49.6%) in the second year of follow-up reported the LLIN being lost to follow-up as a result of LLIN damage. Of those 78 households not retaining a net because it was destroyed, being torn and having holes accounted for 70.5% of net damage; being eaten by rodents accounted for 20.5%.

Based on univariate analyses the only characteristic that varied significantly between households that retained an LLIN from the 2008 campaign compared with those that did not was the time since the campaign in years ($P = 0.0001$). Wealth quintile, LLIN brand, or household locations were not significant (data not shown).

LLIN damage. We took 447 LLINs from the 561 households interviewed to the INS laboratory for damage assessment: two were lost in transit for a total of 445 LLINs available for hole counting in the laboratory over 3 years of follow-up. The proportion of LLINs with damage increased each year. Overall, there was at least one hole, stitch or repair in 414 (93.0%) LLINs: 124 (83.8%), 156 (95.7%), and 134 (100%) at years 1, 2, and 3 of follow-up, respectively ($P < 0.0001$). In 412 LLINs (92.6%), there was at least one hole.

TABLE 1

Outcome of the follow-up visits over 3 years, after a long-lasting insecticidal net (LLIN) mass distribution campaign in Nampula Province, Mozambique 2008

Interviews	Year			Total
	2009	2010	2011	
Expected to conduct	210	240	270	720
Lost to follow-up (%)	48 (23)	43 (18)	62 (23)	153 (21)
Conducted (%)	162 (77)	197 (82)	208 (77)	567 (79)
Retained LLIN in household (%)	149/162 (92)	164/197 (83)	134/208 (64)	447/567 (79)

TABLE 2
Holes counted in long-lasting insecticidal nets (LLINs) over the 3 years of follow-up, by brand*

Follow-up time	No. of LLINs	Holes in Olyset LLINs			No. of LLINs	Holes in PermaNet 2.0 LLINs		
		Median no. of holes	Mean no. of holes	95% confidence limits		Median no. of holes	Mean no. of holes	95% confidence limits
1 year	50	18	28.3	20.4–36.3	73	6	13.2	9.5–16.9
2 years	56	53.5	67.4	53.7–81.1	97	18	34.5	26.4–42.6
3 years	47	71	87.7	71.5–103.8	86	35.5	43.0	35.3–50.8

*Excludes three outlier nets: 2 Olyset LLINs from year 2 with 1,161 and 2,607 holes, and 1 PermaNet 2.0 LLIN from year 3 with 3,403 holes for a total of 412 LLINs.

Table 2 presents the results of the hole counting conducted in the laboratory by number of holes by LLIN brand in each year of follow-up. A total of 412 LLINs with at least one hole were assessed: three LLINs were removed from the analysis because they were severely damaged (appearance of “Swiss cheese”) with hundreds of holes and would likely have skewed the results. Olyset LLINs had a significantly greater mean number of holes by year compared with PermaNet 2.0 LLINs (P values: year 1 = 0.001; year 2 < 0.0001; year 3 < 0.0001). It can be noted that on average, by year 1 of follow-up, PermaNet 2.0 LLINs had 13 holes (median 6), whereas Olyset LLINs had 28 (median 18). By the second and third years of follow-up, the LLINs had on average between 30 and 70 holes (medians 18 and 53.5), and 40 and 80 holes (medians 35.5 and 71), respectively.

Table 3 presents the results of the hole counting at the INS laboratory among 409 LLINs using the WHOPES hole size categories for each year of follow-up, broken down by LLIN brand. The number of holes is greater for Olyset LLINs when compared with PermaNet 2.0 LLINs for every year and all hole categories. Although the acquisition of new small holes (< 2 cm) increases every year for both brands it appears that Olyset LLINs acquire progressively large holes (> 25 cm) each year whereas for PermaNet 2.0 LLINs this trend is less clear.

Overall, after 3 years of follow-up we found an association between any LLIN damage and LLIN brand (98.7% of Olyset compared with 89.9% of PermaNet 2.0, $P = 0.0006$) and inland (96.2%) compared with coastal (87.2%) household locations ($P = 0.0004$) but not with wealth quintile ($P = 0.9$) or small village versus remote village location ($P = 0.8$).

Overall, the most commonly reported cause of damage was rodents eating the LLINs (42.2%); securing the LLIN when going to sleep or while entering/exiting the LLIN, a sharp object or a lantern (32.3%, 17.7%, 15.5%, and 14.1%, respectively)

were other causes reported. The only factor significantly associated with an LLIN brand was securing an Olyset when going to sleep compared with PermaNet 2.0 (38.7% and 28.4%, respectively, $P = 0.03$); there were no associations with wealth quintile.

We found that most of the holes were located in the lower quarter of the LLIN (< 45 cm from the bottom). When analyzed by individual hole size categories, the hole location pattern follows the overall location pattern, with most holes in the bottom quarter of the LLIN. The exception is that of the very large holes, > 25 cm, which were less consistently located in the bottom; although the number of holes in this category is much less than in other hole categories.

Figure 3 depicts the WHOPES pH of the LLINs by a box and whisker plot over the 3 years of follow-up and by brand. Similar to Table 2, this figure shows the significant difference between the two brands of LLINs, with Olyset LLINs having more holes, or relative surface area represented by holes, than PermaNet 2.0 LLINs.

DISCUSSION

The results of this prospective evaluation of LLINs distributed in a mass campaign in Nampula Province, Mozambique in 2008 show relatively low LLIN attrition (25%) after 3 years of follow-up and varying degrees of physical damage over time. The physical damage, represented as holes with minimal evidence of repairs, was already evident at 1 year after the campaign and differed significantly by LLIN brand. The LLINs distributed in rural Mozambique were retained by households despite the damage incurred during their use. This damage starts within the first year of the LLIN’s “life.” Among households that discarded LLINs (those lost to follow-up) this was reportedly due to damage; therefore, our findings might underestimate LLIN durability as we were not

TABLE 3
Number of holes in each of four different size categories in long-lasting insecticidal nets (LLINs) over the 3 years of follow-up, by brand*

Follow-up time, by brand	Hole size category	Olyset				PermaNet 2.0			
		Sum of holes	Median no. holes per LLIN	Mean no. holes per LLIN	95% Confidence limits	Sum of holes	Median no. holes per LLIN	Mean no. holes per LLIN	95% Confidence limits
1 year Olyset $N = 50$ PermaNet 2.0 $N = 73$	≤ 2 cm	841	11.5	16.8	12.0–21.6	748	5	10.2	7.2–13.3
	> 2 and ≤ 10 cm	472	5	9.4	6.6–12.3	176	1	2.4	1.6–3.2
	> 10 and ≤ 25 cm	80	1	1.6	0.9–2.3	26	0	0.4	0.2–0.5
	> 25 cm	24	0	0.5	0.1–0.8	12	0	0.2	0.0–0.3
2 years Olyset $N = 56$ PermaNet 2.0 $N = 97$	≤ 2 cm	2,282	30	40.8	32.8–48.7	2,418	13	24.9	19.0–30.9
	> 2 and ≤ 10 cm	1,251	15	22.3	15.9–28.8	811	5	8.4	6.3–10.5
	> 10 and ≤ 25 cm	177	2	3.2	2.3–4.0	86	0	0.9	0.5–1.3
	> 25 cm	66	0.5	1.2	0.7–1.6	28	0	0.3	0.1–0.5
3 years Olyset $N = 47$ PermaNet 2.0 $N = 86$	≤ 2 cm	2,203	41	46.8	38.3–55.4	2,489	23	28.9	23.7–34.1
	> 2 and ≤ 10 cm	1,505	24	32.0	25.3–38.8	1,047	7	12.2	9.3–15.0
	> 10 and ≤ 25 cm	273	3	5.8	3.8–7.8	131	1	1.5	1.1–2.0
	> 25 cm	139	2	3.0	1.8–4.1	35	0	0.4	0.2–0.6

*Analysis excludes three outlier nets: 2 Olyset LLINs from year 2 with 1,161 and 2,607 holes, and 1 PermaNet 2.0 LLIN from year 3 with 3,403 holes for a total of 412 LLINs.

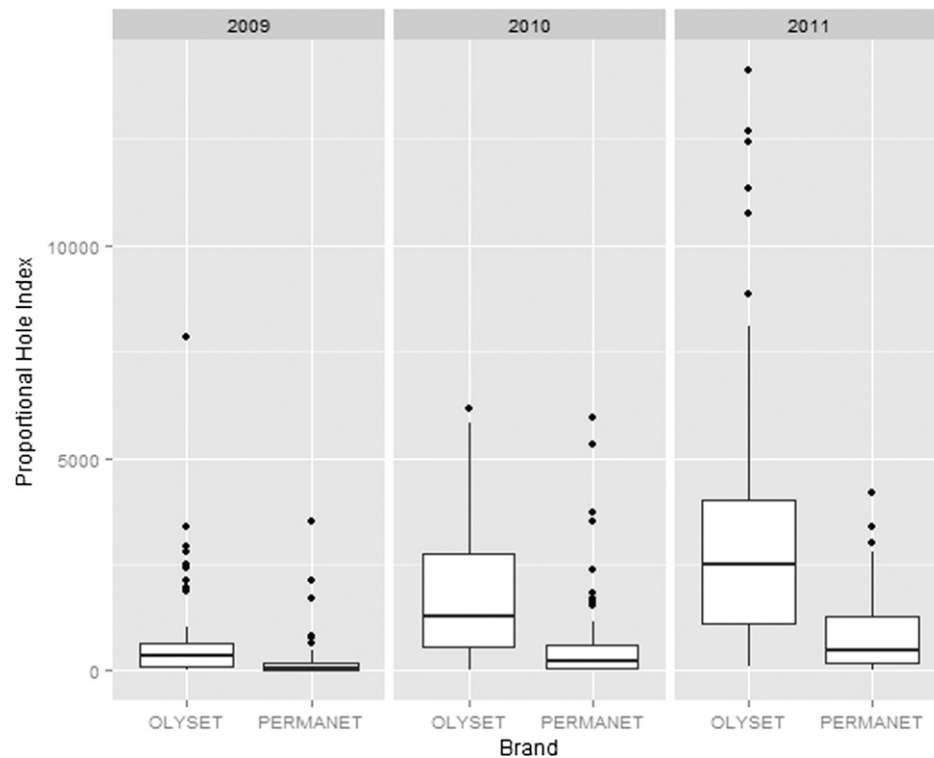


FIGURE 3. The proportional hole index of the long-lasting insecticidal nets (LLINs) presented in a box and whisker plot over the 3 years of follow-up and by brand.

able to assess the LLIN damage of those lost to follow-up. Households that retain their damaged LLINs possibly do so beyond the “effective lifespan” of the LLIN, which would thereby render the household members at risk of malaria despite owning an LLIN. Although we were able to quantify the physical durability of the LLINs after 3 years of follow-up, the degree to which the physical damage of an LLIN impacts its ability to protect the individuals sleeping under it from a malaria-infected mosquito is not well understood.^{13,23,24,28–33} The PHI, which provides a standardized measure to compare holes among different LLINs by assigning a weight, which is the midpoint diameter to an estimated hole size,^{8,10–13,23,34} confirmed differences in durability between these two major brands of LLINs. It would seem obvious that very large holes, such as those > 25 cm, would easily allow for a mosquito to enter an LLIN. However, it is less obvious for holes that are on the other end of the spectrum, such as < 2 cm or even up to 10 cm. Moreover, the effect of one large hole on mosquito penetrability as compared with many smaller holes is not known. Studies assessing mosquito penetration through different sizes of LLIN holes are necessary to better understand our findings and when LLINs should be replaced if they are to provide protection against malaria. Finally, the effect of the LLIN coverage at the community level on individual protection for persons sleeping under an intact versus damaged LLIN³⁵ and vector susceptibility^{24,31,33} may need to be considered.

At 1 year after the LLIN distribution campaign, a greater proportion of Olyset LLINs had holes (98.0%) compared with PermaNet 2.0 LLINs (76.2%). As an example, when considering just larger holes, we found that Olyset LLINs had a mean of 1.6 holes roughly the size of a fist to a head and 0.5 holes

greater than the size of a head, whereas PermaNet 2.0 LLINs had 0.4 and 0.2 holes of the same sizes (1 year of follow-up). This finding is in contrast to early durability assessments of Olyset LLINs, which were found to have few holes after 7 years of use¹⁹; although findings from this and other multi-country assessments may not have taken into account LLIN attrition.³⁶ Over time, the differences between the brands remained consistent, with Olyset LLINs having approximately double the mean number of holes by size and year of follow-up.

We relied on the household respondent’s recall to determine the cause of LLIN damage; this represents the perceived cause of damage. Moreover, this information is at the LLIN level and not for each hole. We found that rodents reportedly played an important role in LLIN damage along with the setting-up of the LLIN for nightly use. The location of the holes on the LLINs is consistent with respondents’ reports that securing of the LLINs at night as one of the major causes of the LLIN holes.³⁷ In addition, the survey teams observed that in rural households in Nampula LLINs are commonly secured at the bottom of the LLIN to the reed mat or other material used as a sleeping space. Further analysis is pending to identify potential associations of LLIN damage with factors including washing and frequency of use. Microscopic examination of the holes, currently ongoing, could provide objective information as to the causes of individual holes.

Our evaluation had some limitations, mainly in terms of the tagging of the LLINs. Although efforts were made to secure the bar-coded tag to the LLIN, it was not always present at the time of the follow-up survey. In these situations, the survey teams were instructed to ascertain the source of the LLINs in the household from the respondents, considering that at 1 month after the LLIN distribution campaign, MRC

volunteers had identified a tagged LLIN in the household during the “hang-up/keep-up campaign” and mapped the household coordinate. In addition, information collected on the cause of the damage was not at an individual hole level but rather at the LLIN level, which makes the subjective assessment of the cause of damage unreliable and especially when comparing brands.

In summary, although other measurements of LLIN durability, such as insecticidal effectiveness and insecticide levels, are pending on these same LLINs, in terms of the attrition and physical durability, we can conclude that most LLINs distributed through a mass campaign in 2008 were retained despite damage that started early on in the life of the LLINs. We found that PermaNet2.0 had fewer and smaller holes than Olyset in this rural Mozambique setting. This information may be relevant to the Mozambique NMCP in terms of the performance of the two brands of LLINs, based on physical durability, for future LLIN procurements for mass distribution through campaigns. Our findings are limited to the two LLIN brands, Olyset and PermaNet 2.0, distributed during the mass campaign in 2008; other LLIN brands could perform differently under the same or different conditions. Therefore, our results may not be extrapolated to other LLIN brands, even in similar settings. Moreover, more research still needs to be conducted to determine how the damage to an LLIN, of any brand, affects its ability to prevent and reduce transmission. Manufacturers need to clarify their guarantee to prospective LLIN purchasers of the “performance” of their products for 3 and 5 years because currently this guarantee is based on insecticidal activity and burst strength tests performed in a controlled setting. As more field evaluations of LLINs durability are conducted by national malaria control programs, more evidence of the performance, in terms of the physical durability, will inform these necessary changes.

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