RNAL

RESEARCH Open Access

Physical durability of PermaNet 2.0 long-lasting insecticidal nets over three to 32 months of use in Ethiopia

Aprielle B Wills[1], Stephen C Smith[2], Gedeon Y Anshebo[3], Patricia M Graves[1,5*], Tekola Endeshaw[3], Estifanos B Shargie[3], Mesele Damte[3], Teshome Gebre[3], Aryc W Mosher[1], Amy E Patterson[1], Yohannes B Tesema[4], Frank O Richards Jr[1] and Paul M Emerson[1]

Abstract

Background: Ethiopia scaled up net distribution markedly starting in 2006. Information on expected net life under field conditions (physical durability and persistence of insecticidal activity) is needed to improve planning for net replacement. Standardization of physical durability assessment methods is lacking.

Methods: Permanet®2.0 long-lasting insecticidal bed nets (LLINs), available for distribution in early 2007, were collected from households at three time intervals. The number, size and location of holes were recorded for 189 nets used for three to six months from nine sites (2007) and 220 nets used for 14 to 20 months from 11 sites (2008). In 2009, a "finger/fist" sizing method classified holes in 200 nets used for 26 to 32 months from ten sites into small (<2 cm), medium (> = 2 to < =10 cm) and large (>10 cm) sizes. A proportionate hole index based on both hole number and area was derived from these size classifications.

Results: After three to six months, 54.5% (95% CI 47.1-61.7%) of 189 LLINs had at least one hole 0.5 cm (in the longest axis) or larger; mean holes per net was 4.4 (SD 8.4), median was 1.0 (Inter Quartile Range [IQR] 0–5) and median size was 1 cm (IQR 1–2). At 14 to 20 months, 85.5% (95% CI 80.1-89.8%) of 220 nets had at least one hole with mean 29.1 (SD 50.1) and median 12 (IQR 3–36.5) holes per net, and median size of 1 cm (IQR 1–2). At 26 to 32 months, 92.5% of 200 nets had at least one hole with a mean of 62.2 (SD 205.4) and median of 23 (IQR 6–55.5) holes per net. The mean hole index was 24.3, 169.1 and 352.8 at the three time periods respectively. Repairs were rarely observed. The majority of holes were in the lower half of the net walls. The proportion of nets in 'poor' condition (hole index >300) increased from 0% at three to six months to 30% at 26 to 32 months.

Conclusions: Net damage began quickly: more than half the nets had holes by three to six months of use, with 40% of holes being larger than 2 cm. Holes continued to accumulate until 92.5% of nets had holes by 26 to 32 months of use. An almost complete lack of repairs shows the need for promoting proper use of nets and repairs, to increase LLIN longevity. Using the hole index, almost one third of the nets were classed as unusable and ineffective after two and a half years of potential use.

* Correspondence: pgraves.work@gmail.com
[1]The Carter Center, Atlanta, GA, USA
[5]School of Public Health, Tropical Medicine and Rehabilitation Sciences, James Cook University, PO Box 6811, Cairns, Qld, Australia
Full list of author information is available at the end of the article

Background

Long-lasting insecticidal bed nets (LLINs) are considered a vital component in the worldwide effort to prevent malaria transmission in malaria-endemic countries [1]. In 2007, the World Health Organization's Global Malaria Programme recommended immediate scale up of LLIN distribution from national programmes and partners. As a result, large-scale distribution efforts have been launched to meet this goal, particularly in sub-Saharan Africa, by a host of governments, non-governmental organizations were chosen by convenience sampling from areas that had received nets in batches procured by The Carter Center; the choice was restricted to sites reasonably accessible to vehicles (not more than 30 minutes' walk from a road). The target was 25 nets per site for a total of 200 nets. It was subsequently determined that some collected nets in Kaffa zone (sites G and H) were not from The Carter Center distribution; they were excluded as their time in use was not known.

The second collection was conducted between November and December 2008, and the third from July to November 2009. Because rel.4(t)04tu.e9(t)-19.54

new PermaNet®2.0 replacing the old net. Collected nets were labelled with a unique identifier code and placed individually in plastic bags for storage and transport. The latitude, longitude and elevation were recorded for each household using a GPS receiver (12-Channel Garmin® E Trex™, Garmin International, Olathe, KS, USA). The same *kebeles* were visited in both 2008 and 2009, but different households (the next closest houses to those previously visited in 2008) were selected in 2009.

Nets from the first round of collections were evaluated at the Centers for Disease Control and Prevention (CDC) in Atlanta, USA. Nets from the second and third collections were kept in-country and evaluated at The Carter Center office in Addis Ababa.

Time period of use

The time that nets had been in use was estimated from the reported time (month) of distribution and the known time of collection. Most nets were distributed between March and June 2007 (three to six months before the first collection in 2007), but there was an exception in site J (Dib Bahir *kebele* in Debark *woreda*, North Gondar zone) where the nets were not distributed until four months before the second collection in August 2008. The nets were therefore not grouped by year of collection for analysis, but by "time of use groups" as follows:

Group 1 (three to six months of potential use): comprises nets from the eight collection sites (A through H) in 2007 plus nets from site J collected in 2008–

Table 1 Long-lasting insecticidal bed nets' collection sites

Site	Year of collection	Collection group	Time in potential use (months)	Region	Zone	Woreda	Kebele	Elevation (meters)	No. of TCC nets collected

Table 2 Summary of physical condition of collected nets, by site and time group

Site	Time in potential use (months)	No. of nets	No. (%) nets undamaged	No. (%) nets with seams intact	No. (%) nets with repairs	No. of holes (0.5 cm) per net		Hole size (cm)	
						Median (IQR)	Range	Median (IQR)	Range
A	3	25	12 (48)	23 (92)	0	1–2(0)	0-40	1 (1–2)	0.5-18
B	3	25	12 (48)	24 (96)	0	1–5(0)	0-13	1 (1–1)	0.5-13
C	3	25	9 (36)	24 (96)	0	1–3(0)	0-36	1 (1–2)	0.5-10
D	3	25	10 (40)	22 (88)	0	1–6(0)	0-25	1 (1–2)	0.5-13
E	6	25	10 (40)	24 (96)	0	3–9(0)	0-46	1 (0.5-2)	0.5-26
F	6	25	8 (32)	24 (96)	0	3–1(01)	0-28	1 (1–3)	0.5-58
G	3	5	4 (80)	5 (100)	0	0–0(0)	0-3	1 (0.5-1)	0.5-1
H	3	14	7 (50)	14 (100)	0	0.5–2(0)	0-30	1 (1–2)	1-5
J	4	20	14 (70)	20 (100)	0	0–3(0.5)	0-40	1 (1–2)	1-10
	3-6 mths	189	86 (46)	180 (95)	0	1 (0–5)	0-46	1 (1–2)	0.5-13
K	19	20	0 (0)	19 (95)	0	10.5–22(4)	1-114	1 (1–2)	1-60
L	19	20	2 (10)	19 (95)	1 (5)	16 (3.5-26.5)	0-86	1 (1–3)	1-32
M	20	20	4 (20)	20 (100)	0	4–9(1)	0-48	1 (1–2)	1-19
N	19	20	7 (35)	18 (90)	0	7–2(04.5)	0-114	1 (1–2)	1-50
P	20	20	6 (30)	16 (80)	0	6–2(0)	0-91	1 (1–3)	1-88
Q	18	20	0 (0)	14 (70)	0	59 –(295.5)	1-263	1 (1–2)	1-120
R	18	20	5 (25)	18 (90)	0	14 (3.5-48.5)	0-144	1 (1–3)	1-155
S	17	20	3 (15)	16 (80)	1 (5)	10.5–18(3.5)	0-138	1 (1–2)	1-34
T	18	20	0 (0)	13 (65)	0	17 –(5193.5)	1-128	1 (1–2)	1-36
U	20	20	5 (25)	15 (75)	1 (5)	6–3(71.5)	0-524	2 (1–3)	1-180
J	14	20	0 (0)	19 (95)	1 (5)	14.5 (5.5-36)	1-52	NA	NA
	14-20 mths	220	32 (15)	187 (85)	4 (2)	12 (3–36.5)	0-524	1 (1–2)*	1-180*
K	29	20	1 (5)	18 (90)	0	22–3(60.5)	0-47	NA	NA
L	29	20	3 (15)	20 (100)	1 (5)	10.5–25(1.5)	0-133	NA	NA
M	30	20	4 (20)	18 (90)	0	5.5 (2.5-20.5)	0-60	NA	NA
N	28	20	1 (5)	20 (100)	1 (5)	11.5 (3.5-27.5)	0-149	NA	NA
P	27	20	0 (0)	18 (90)	0	23.5 (13.5-53)	2-116	NA	NA
Q	30	20	0 (0)	14 (70)	0	77.5 (37.5-142.5)	7-207	NA	NA
R	30	20	2 (10)	19 (95)	0	26.5 (6.5-87.5)	0-236	NA	NA
S	28	20	2 (10)	17 (75)	0	23 (11.5-53)	0-187	NA	NA

Table 2 Summary of physical condition of collected nets, by site and time group (Continued)

T	26	20	0 (0)	19 (95)	1 (5)	66.5 (39.5-131.5)	1-399	NA	NA
U	32	20	2 (10)	20 (100)	1 (5)	18.5 (5-24)	0-2690	NA	NA
	26-32 mths	200	15 (7.5)	183 (92)	4 (2)	23 (6-55.5)	0-2690	NA	NA

*excludes site J in 14 to 20 month group (exact hole size not available for nets collected in 2009). NA not available.

areas to be 4, 36 and 225 sq cm respectively, giving multiplication factors of 1, 9 and 56 for small, medium and large holes to arrive at the proportionate hole index.

Since this study used three hole size categories with approximately the same cut-offs as Kilian et al. [10], a proportionate hole index for each net was estimated as follows:

Hole index = [number of small holes < 2 cm + (9 × number of medium holes >= 2 cm to <= 10 cm) + (56 × number of large holes > 10 cm)]. Hole indices per net were averaged for site and time-group summary estimates.

Nets were classified into four levels based on physical condition using the hole index, following Kilian et al.

Although there were more nets with holes as the time periods progressed, and the number of medium and large holes increased (Table 3), the relative number of holes of different sizes (small <2 cm; medium > =2 and < =10 cm; large >10 cm) did not change between the time periods of collection (Figure 5).

Physical evaluation– location of holes

Table 3 Summary of hole size distribution and hole index for collected nets

Site	Time in potential use (months)	No. of nets	Mean no small holes per net	Mean no medium holes per net	Mean no large holes per net	Mean proportionate hole index per net
A	3	25	2.2	1.7	0.1	24.4
B	3	25	2.0	0.6	0.04	9.2
C	3	25	1.6	1.4	0.04	16.8
D	3	25	2.2	1.7	0.1	21.8
E	6	25	4.2	2.2	0.2	37.8
F	6	25	3.6	2.8	0.3	44.4
G	Bk4ai ToT02e-8064.7.5(e)-10(ven)-319(af)0e. Tc [(e)183n(et)]22p3o.hJ(G)-8(0.04)-7581.3(/. [(e)187 [(F)-4049.7433 TD [(G)-3804 a7433T02e-					

"poor" were 3%, 28% and 45% at the three time periods respectively.

Discussion

This investigation was unusual in that net evaluation began very shortly after distribution. Since LLINs are expected to last for multiple years, most prior studies have been of nets a year or more after distribution. However, for programme planners preparing for replacement campaigns, it would be useful to have meaningful data about nets in the field and their rate of deterioration as early as possible. Results from this study showed that in as little as three to six months, a quantifiable picture began to emerge regarding the physical deterioration of nets in the field. Future LLIN monitoring efforts can therefore start less than a year after distribution in order to give planners a head start on developing timetables for replacement.

Although some nets were still in good physical condition even after a year-and-a-half in this study, a substantial proportion showed significant deterioration: 68% had holes and 28% were classed as 'mediocre' or 'poor' by hole index at 14 to 20 months of use. The distribution of holes per net was highly skewed, with a few nets having many holes and most nets with few holes. For this reason, statistical descriptions of overall condition of a group of nets are better described by the median and not the mean number of holes, the latter being disproportionately impacted by the existence of a few heavily damaged nets. However, the size of holes must be taken into account as well: one large hole may be as problematic (or even more so) than a large number of small holes, since large holes can let more mosquitoes inside of the net without contacting the insecticidal fibres.

The two schemes proposed [9,10] to estimate a standardized hole index differ in both the number of size categories and the relative factors applied to each. In the first scheme, WHO [9] recommended four size categories of 0.5 to 2 cm, 2 to 10 cm, 10 to 25 cm and >25 cm, with midpoint hole diameter of 1.25, 6, 17.5 and 30 cm respectively. The relative multiplication factors based on corresponding hole areas for these groups are 1, 23, 196 and 578. Secondly, Kilian et al. [10] and Batisso et al. [11] used three size categories <2 cm, 2 to 10 cm and >10 cm (finger, fist and head). They estimated average hole areas to be 4, 36 and 225 sq cm respectively, giving multiplication factors of 1, 9 and 56 for small, medium and large holes to arrive at the proportionate hole index. The current study commenced before either of these schemes was published, but elected to use the method of Kilian et al. [10] and Batisso et al. [11] for categories similar to those used here, and to enhance comparability between studies in Ethiopia.

A limitation of this study is that net attrition (complete loss of nets through disposal, diversion to other use, sale, or donation to others outside the household) was not measured, so net deterioration and loss may have been underestimated. Attrition has been estimated to be as high as 32% over three years (Batisso et al. [11]). Other limitations include the convenience sampling method for the sites and households, and the fact that the sites were at a range of altitudes, so net use (and as a result, net wear) may differ significantly depending on mosquito populations and perceived risk of malaria.

Repairs to nets that had developed holes were rarely observed in this study. Low repair rates were also reported by Smith et al. [6], Kilian et al. [10] and Shirayama et al. [12] so this appears to be a widespread issue. However, Bhatt et al. [13] found a total of 750 repairs, or average 1 repair per LLIN, in the forms of stitches (63.9%), knots (35.8%) and patches (0.3%) in their evaluation of Interceptor® LLINs (n = 932) in central India. It is likely that longevity of nets can be significantly improved simply by making repairs to them and perhaps by extension, comparison for our study is to that of Batisso *et al*. [11] in Ethiopia, who observed that after three years, 70% of nets were still in 'good' or 'fair' condition as defined by a