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Article

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Summary: This study aimed to evaluate the durability of new bed nets with two insecticides incorporated into fibres (Interceptor® G2, Royal Guard® and Olyset™ Plus) compared to standard nets (Interceptor®) which contain a single insecticide (pyrethroid only). These bed nets were distributed in Misungwi district Tanzania in February 2019 for daily use. The number of bed nets allocated in each of the selected villages depended on the number of occupants in each house (one net for two people). After distribution nets selected for the study were labelled with the household number and net number to facilitate follow-up which was done at 6, 12, 24, 30 and 36 months post distribution. During surveys, householders were informed to use the net until the next visit. In a real life situation, these nets were supposed to protect the user for three years but this was not the case in this study because all nets had life span of less than three years. Most respondents (through questionnaire) reported that they discarded their nets due to wear and tear and this effect was more severe in clusters with Olyset™ Plus nets than clusters with standard Interceptor® net and other dual insecticide nets.

Abstract: Long-lasting insecticidal nets (LLINs) have been the main contributor to the reduction of malaria in the past two decades in sub-Saharan Africa. Development of pyrethroid insecticide resistance threatens the effectiveness of these LLINs, especially when nets become holed and the insecticide decays. Three classes of dual active ingredient (AI) LLINs, have been assessed for their physical durability as follows: 1) Royal Guard®, combining pyriproxyfen, which is known to disrupt female reproduction and fertility of eggs, and a pyrethroid alpha-cypermethrin; 2) Interceptor® G2, two adulticides with differing modes of action; chlorfenapyr and alpha-cypermethrin; 3) Olyset™ Plus incorporates permethrin (pyrethroid) and a synergist, piperonyl butoxide, to enhance the potency of pyrethroid insecticides; all nets were compared to standard pyrethroid only net (Interceptor®). About 40,000 nets of each type were distributed in February 2019 to different villages in Misungwi. A total of 3072 LLINs were followed at 6, 12, 24, 30 and 36 months to assess survivorship and fabric integrity in a community setting. The median functional survival were less than three years with Interceptor®, Interceptor® G2 and Royal Guard® having 1.9 year each and 0.9 years for Olyset™ Plus . After 36 months, 90% of Olyset™ Plus and Royal Guard® and 87% of Interceptor® G2 were no longer present (thrown away) in the households due to wear and tear, compared to 79% for standard Interceptor®. Short life spans of all assessed LLINs were driven by material of the net, rather than social economic status and housing material. All dual AI LLINs have a poor textile durability with Olyset™ Plus being the worst of the three.

1. Introduction

Pyrethroid-only insecticide-treated nets (ITNs) were the cornerstone for malaria vector control until recently when pyrethroid resistance emerged and now threatens the future of malaria vector control. The effectiveness of long-lasting insecticidal nets (LLINs) is also influenced by multiple other factors, including net fabric durability, insecticidal availability, net usage and handling (1). In areas with intense pyrethroid resistance, if LLINs are damaged, mosquitoes may penetrate the net holes and feed on human hosts, potentially transmitting malaria (2). The presence of LLINs with intact fabric (undamaged), even if untreated, provide a physical barrier and can prevent human-vector contact and reduce human blood-feeding (3, 4); however, treating bed nets with insecticide can provide additional protection by adding a chemical barrier (1).

When nets develop holes, users may perceive them as unprotective and discard them which leads to reduction in usage (5, 6). In Ethiopia, LLINs surveyed were reported having shorter household survival times (19 months) and the major causes were attrition and physical damage (7). The attrition rate of the sub-sample (77.1%) of the nets distributed in mass campaign was 48.8 % after three years with the reason that the net were too torn (physical damage) while 13% were used in other location and 12.8% were used for the other activities (7). Increased attrition rate due to fabric integrity has impacted malaria transmission in malaria endemic regions in Kenya, where 40% of nets were extremely damaged after 12 months post-distribution (8). In Tanzania, attrition was even higher, with less than 83% of bed nets distributed for daily use no longer present in households after 3 years, giving a medium survival rate of 1.6 and 1.9 years for Olyset™ Plus and Olyset™ net, respectively (9). These findings contrast with World Health Organization (WHO) assumptions of nets being present and functional for three years in the community (10). After three years of longitudinal monitoring in north-west Tanzania, 37% and 55% of Olyset™ net and Olyset™ Plus were considered extremely damaged (un-serviceable according WHO categories), respectively (9). The results from structured questions administered during a survey in Zambia, reported that the nets developed holes quickly due to the size (small nets compared to bed size) and material of the net (11).

Different studies have reported that when insecticide in the netting material decreases and nets acquires holes, users have no or minimal protection as the mosquitoes can penetrate and blood fed (2, 11). The study conducted in Zambia showed that poor fabric integrity of standard pyrethroid nets threatened their effectiveness against *Anopheles arabiensis* (11), while another one in Tanzania, demonstrated that increased holes surface was associated with higher number of *An. gambiae* found inside the net (2).

Washing and drying LLINs has been reported to be among the factors that contribute to reduced LLIN insecticide concentration and development of holes in the community (12). Generally, social economic status is one of the factors affecting net handling. With reference to a study done in Bouaké, Côte d'Ivoire, household owners with primary/higher education had better knowledge about how to manage (tuck in on bed, washing, drying) nets than those who reported having received limited education (13).

New classes of ITNs have been recommended by WHO (14) recently as they showed superior protection against malaria compared to standard LLINs in various cluster-randomized controlled trials (cRCTs) (Muleba (15), Misungwi (16), Benin (17) and Uganda (18)). ITNs combining the synergist, pipernoyl butoxide (PBO) and pyrethroid were recommended and deployed since 2018; and in 2023, two other ITNs, belonging to a new vector control tool class, dual-active ingredient (AI) ITNs, combining two insecticides, either chlorfenapyr and a pyrethroid for Interceptor®G2 or pyriproxyfen and a pyrethroid for Royal Guard®, received WHO approval (14). Although these nets performed well in cRCTs in Tanzania (16) and Benin (17), the impact was reduced over time as net usage dropped from 72% to 41% after 2 years in Tanzania and 77% to 61% in Benin. As those nets are

being scaled up, net durability including fabric integrity and survivorship (attrition) (19) should be assessed, to inform epidemiological outcomes and how these interventions can be incorporated into vector control programmes. As part of the cRCT in Tanzania, this study assessed the survivorship/ attrition rate and fabric integrity of a cohort of 3 dual-AI ITNs (Royal Guard®, Olyset™ Plus and Interceptor® G2) over 3 years of community use, compared to pyrethroid only ITNs.

2. Methodology

Characteristics of the long-lasting insecticidal nets (LLINs) tested

The present study was nested in a large cRCT conducted Misungwi district, Tanzania (16). In the cRCTs, four types of nets were distributed in February 2019 among 84 clusters (21 clusters per intervention arm). The LLINs under evaluation were 1/ Royal Guard®, (Disease Control Technologies, LLC), a mixture LLIN made of polyethylene incorporating 225 mg/m^2 pyriproxyfen and 261mg/m^2 alpha-cypermethrin, which is known to disrupt female reproduction and fertility of eggs; 2/ Interceptor® G2, a mixture LLIN made of polyester coated with a wash-resistant formulation of 200 mg/m^2 chlorfenapyr and 100 mg/m^2 alpha-cypermethrin; 3/ Olyset™ Plus (Sumitomo Chemicals), a LLIN combining piperonyl butoxide (PBO; 400mg/m^2) and the repellent pyrethroid permethrin (800 mg/m^2) incorporated into polyethylene fibres, to enhance the potency of pyrethroid insecticides; 4/ Interceptor®; (BASF Corporation), a single pyrethroid-treated LLIN with alpha-cypermethrin at a target dose of 200 mg/m^2 coated onto polyester filaments (reference intervention) (20).

Study area

Misungwi district covers an area of 2579km^2. The estimated total population in the area is 467,867 found in 78 villages. There has been a 2.9% annual population increase between 2012 to 2022 (21). The previous intervention in the area was a standard LLIN mass campaign conducted in 2015, indoor residual spraying (IRS) using pirimiphos-methyl from 2013 to 2017 and larviciding using Bti in 2018 (9, 22). The major malaria vector species found in the area are *An. funestus* complex, *An. gambiae* sensu stricto and *An. arabiensis.* Details of the Misungwi cRCT has been published previously (16, 20). For the present study a total of 20/84 study clusters from the cRCT were selected for assessment of LLIN attrition and fabric integrity (Figure 1). The full protocol has been published previously (23).
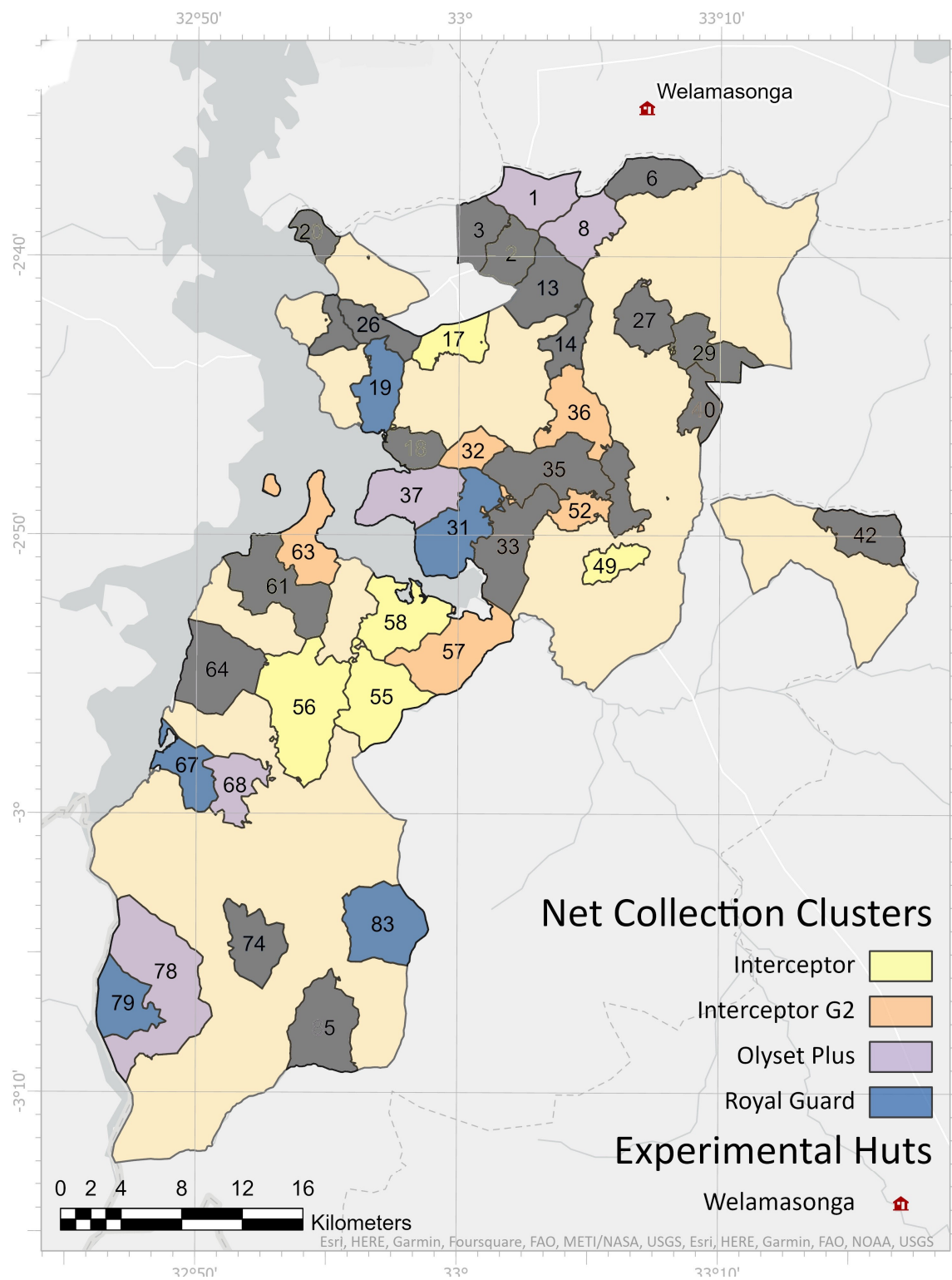
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Figure 1. The clusters selected for net follow-up across Misungwi district: Olyset™ Plus (purple), Interceptor® G2 (orange), Interceptor® (yellow) and Royal Guard® (blue).

Study design

This was a prospective cohort study which followed nets for three consecutive years. After LLINs distribution a census/enumeration of household in hamlet was completed as part of cRCT and each household were given unique identification numbers. Selected study LLINs were recorded and labeled with household number and net number one month post distribution. The study nets were

sampled at 6, 12-, 24-, 30- and 36-months post-distribution; during each time point physical durability (attrition and integrity) was assessed using a structured questionnaire and templates for hole assessment, administered to each household.

Sample size

Sample size calculations were performed using the power log rank command in Stata v.15.1. A total of 750 LLINs per net type from 5 clusters per arm (i.e., 150 per cluster) allow detection of a 9.4% absolute difference (hazard ratio = 0.8651) in LLIN attrition rates assuming an attrition rate in the control of 70% over the 3 years. This assumes an intra-cluster correlation coefficient (ICC) of 0.05.

Attrition rate

After distribution, all the selected nets were labeled with the household number and a net number to create a master list. Up to three nets from each selected households (HH) (total of 250 HH were selected) were assessed in 5 clusters per arm (20 clusters total) at 6, 12-, 24-, 30- and 36-months post-distribution. The head of the household was consented before net inspections and those who agreed to be part of the study were asked about social economic status, housing materials and condition of the net.

In this study, attrition rate was defined as the number of nets which were not present in the household due to wear and tear or other causes (10). The reverse of attrition rate was survivorship which include all nets present in the household during survey. All cause of attrition were assessed using structured questionaire. Differences in attrition rate were assessed as per WHO guidelines (24). The attrition rate was assessed in 750 study nets per arm and measured by physical observation of the net in each room. If the net was not in possession, a follow-up question about the net location was asked. All observed nets were recorded, and the householder was asked if the net was used for its intended purpose.

Fabric integrity

Fabric integrity was defined as physical state of net to estimate bite protection. During surveys the structured questionnaire was administered to each household and thereafter, each net was taken outside the room and hung in the frame by a trained technician. The nets were split into four different zones and holes were assessed using a hole template. The number and size of hole including tears in the netting and split seams by location and size was classified into four categories: smaller than a thumb (0.5 – 2cm ~ hole size 1), larger than a thumb but smaller than a fist (2 – 10cm ~hole size 2), larger than a fist but smaller than a head (10 – 25 cm ~hole size 3) and larger than a head (>25 cm ~hole size 4). Hole sizes greater than 0.5 cm were recorded (25). The holes were counted from zone one (bottom part of the net), upwards to the roof section. All data were recorded in Open data kit (ODK) and therafter the net was returned to the room and the user was instructed to use the net until the next visit.

Data analysis

All analyses were done using Stata version 15. Household characteristics were summarised using proportional statistics. There were an additional 6 to 12 houses visited during the survey period and these nets were included in the analysis of consent results but not in the functional survival. Hole size was calculated as π x length x width and weighted to calculate proportionate hole index as follows: pHI = (1 x number of size 1 holes) + (23 x number of size 2 holes) + (196 x number of size 3 holes) + (576 x number of size 4 holes). Proportionate hole index was then categorized based on recommended cut-off points in three categories (26) (Appendix 1). The sum of the pHI in good and damaged catergory were presented as serviceable LLIN while too torn cartegory were termed as unserviceable. Furthermore, the proportion of nets with at least one hole of any size was calculated per net brand per time point. Attrition rate was calculated as the proportion of study nets not present in the household during the survey period due to wear and tear and other reason divide by all study

nets originally received excluding net lost to follow-up. Reasons of net loss were also investigated (26). For functional survival, we considered net present at each time point in serviceable conditions while survivorship were considered as net present in the household during survey period regardless of pHI category.

Cox proportional regression models were fitted to predict the median functional survival and survivorship of each net and its hazard ratio. Functional survival was defined as a net still in serviceable condition, with the hole area <643cm, that was still in possession during the time of survey. Survival time was calculated as the duration between start of follow-up until when the event occurred (net loss) in years. For all physically inspected nets, the survey time was taken as the time of event. If the net was not observed, the respondent was asked to estimate when net was lost or disposed/given away.

Ethical statement

This study was nested in larger cRCT conducted in Misungwi. The cRCT received ethical approval from Kilimanjaro Christian Medical Collage, National Institute for Medical Research (NIMR/HQ/R.8a/Vol.IX/2743) and London School of Hygiene and Tropical Medicine (**Ref:** 16524). Informed consent to explain the purpose (objective) and nature of the study was read in Swahili language and also translated to the local language if the household head did not understand Swahili. For those who agreed to consent, a signature or fingerprint was taken.

3. Results

Study LLIN and household enrollment

A total of 1,154 households were recruited for follow-up. Amongst these houses, 3,072 study nets were enrolled and labelled of which 767 were standard Interceptor®, 772 Interceptor® G2, 766 Olyset™ Plus and 767 Royal Guard® (see Figure 2, Table 1).

The total household selected and labeled one month post distribution for durability were 1,154 however; there were additional houses visited per survey; 12 houses at 6 and 24 months which make a total of 1,166 houses respectively, 11 houses at 12 months which make a total of 1,165 houses, 6 houses at 30 months make a total of 1,160 houses and 10 houses at 36 months which make a total of 1,164 houses (Figure 2) consented. The number of people sleeping in houses and sleeping places were similar between study arms as well as population age distribution (Table 1). More than half of household heads had a primary education, and this was comparable across study arms. The house structures and characteristics was similar, with burnt brick walls, mud floors and metal sheet roofs being the most common house materials while more than 90% of income was from fishing or farming in all study arms (Table 1).

At each visits, consent was given in 938 (80%); 1,071 (92%); 1,039 (89%); 1,160 (83%) and 882 (76%) households at 6-, 12-, 24-, 30- and 36 respectively (see Figure 2). The remaining were either dwelling not found/vacant, refused or return later.
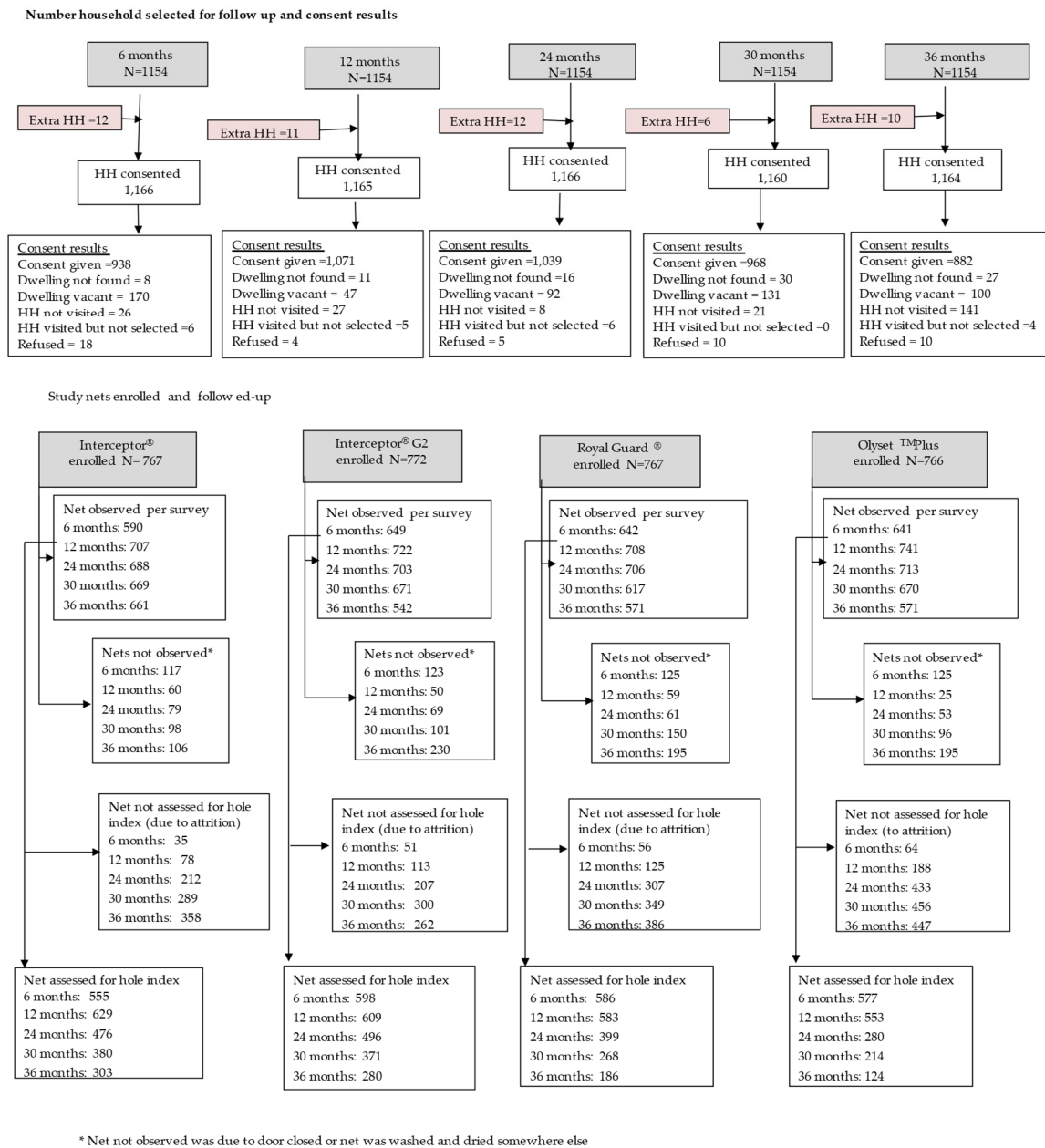
Number household selected for follow up and consent results

Figure 2. Number of household and study nets enrolled for follow-up.

Table 1. Household and social economic characteristics in the study area.

Characteristics	Interceptor®	Interceptor® G2	Olyset ™Plus	Royal Guards®
Number of participants	6624	6743	6604	6466
Average household size	7.5	7.1	7.6	7.7
Mean sleeping spaces per household	3.7	3.5	3.5	3.6
Mean nets per household	3.5	3.3	3.4	3.3
Age distribution of household members %(95%CI)				
5 years	18.8% (17.9 – 19.5)	17.6% (16.8 – 18.5)	18.6% (17.5 – 19.7)	17.3% (16.4 – 18.2)

5–15 years	33.3% (32.3 – 34.4)	33.3% (32.1 – 34.6)	37.3% (34.6 – 40.1)	35.9% (34.6 – 37.2)
>15 years	47.9% (46.9 – 48.9)	49.0% (47.7 – 50.4)	44.1% (41.9 – 46.2)	46.8% (45.5 – 48.1)
Highest level of education of household head %(95%CI)				
No education	30.7% (27.6 - 34.1)	25.8% (22.8 - 29.0)	28.2% (25.1 - 31.5)	32.6% (29.5 - 36.1)
Primary education	66.6% (63.3 - 69.9)	69.3% (65.9 - 72.4)	69.7% (66.4 - 72.9)	64.6% (61.1 - 67.9)
Housing materials %(95%CI)				
Walls: burned brick	99.4% (98.5 - 99.7)	97.5% (96.2 - 98.4)	98.6% (97.5 - 99.2)	98.9% (97.9 - 99.5)
Floor: mud	61.2% (57.7 - 64.6)	62.4% (58.9 - 65.8)	72.0% (68.8 - 75.1)	69.9% (66.6 - 73.1)
Roof: metal sheet	76.9% (73.8 - 79.7)	70.7% (67.4 - 73.8)	72.4% (69.2 - 75.5)	72.4% (69.1 - 75.4)
Source of income %(95%CI)				
Fishing/farming	98.7% (97.6 - 99.3)	90.4% (88.2 - 92.3)	98.6% (97.5 - 99.2)	98.9% (97.9 - 99.5)

Attrition

During longitudinal surveys, all causes of net attrition rate and losses were assessed (Figure 3 & appendix 2). At six months, majority of the nets lost were either given away to relatives: 39% (95% CI: 23 – 58) for Interceptor®; 33% (95% CI: 20 – 47) for Interceptor® G2 and 15% (95% CI: 8-27) for Royal Guard® or used in another location: 43% (95% CI: 26 – 61) for Interceptor®; 26% (95%CI: 15 – 4) for Interceptor® G2 and 42% (95% CI: 29 – 55) for Royal Guard® except for Olyset™ Plus where most of the nets were thrown away (69%, 95% CI: 59 – 77) at six months.

At twelve months, LLINs given away to relatives, used in another locations and used for other purposes were almost half of lost nets for Interceptor® and Royal Guard®; while for Interceptor® G2 and Olyset™ Plus the majority (66% each net type) of nets were lost because they were discarded. From 24 to 36 months, discarding the net was the main reason of attrition with the highest [87% (95% CI: 84 – 89) and 90% (95% CI: 87 – 92) for Olyset™ Plus and 74% (95% CI: 70 – 78)and 90% (95% CI: 87 – 92) for Royal Guard®, respectively (see Figure 3, appendix 2).

Total attrition (all cause net loss) at 6 months post-distribution was low (6.3%, 95% CI: 5 – 9) for Interceptor® nets compared to dual AI LLINs (Interceptor® G2 9.1% (95% CI: 7 -12), Olyset™ Plus 17.9% (95% CI: 15 – 21) and Royal Guard 10.1% (95% CI: 8 – 13)) irrespective of attrition rate at the same survey period. There was a drastic increase in attrition rate in Olyset™ Plus of which half of the nets were no longer present in the houses compared to Interceptor® net which was not the case for Interceptor® G2 and Royal Guard® at 12 months. At the 24 months survey, 81.9% (95% CI: 79 -85) of Olyset™ Plus and 60.1% (95% CI: 56 – 64) of Royal Guard® were no longer present, compared to Interceptor® net. All attrition rates increased until 36 months with Olyset™ Plus being sinigificantly worst (90.5%, 95% CI: 88 – 93; p<0.001), compared to standard Interceptor® (Table 2).

Table 2. Percent attrition of LLIN surveyed and hazard ratio per net type and net age.

Net type	% all attrition, 95%CI					hazard ratio
	6	12	24	30	36	
Interceptor®	6.3% [5 - 9]	15.9% [13 - 19]	40.6% [37 - 44]	52.8% [49 - 57]	62.9% [59 - 67]	1
Interceptor® G2	9.1% [7 - 12]	21.1% [18 - 24]	43.2% [40 - 47]	57.9% [54 - 62]	63.3% [59 - 67]	1.4 [0.9 - 2.1], p=0.121
Olyset™ Plus	17.9% [15 - 21]	50.7% [47 - 54]	81.9% [79 - 85]	85.2% [82 - 88]	90.5% [88 - 93]	2.8 [1.8 - 4.4], p<0.001

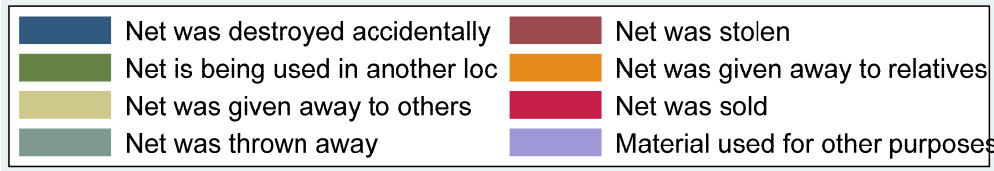|					
Royal Guard®10.1% [8 - 13]	29.9% [27 - 33]	60.1% [56 - 64]	72.6% [69 - 76]	81.9% [79 - 85]	1.5 [0.9 - 2.4], p=0.078
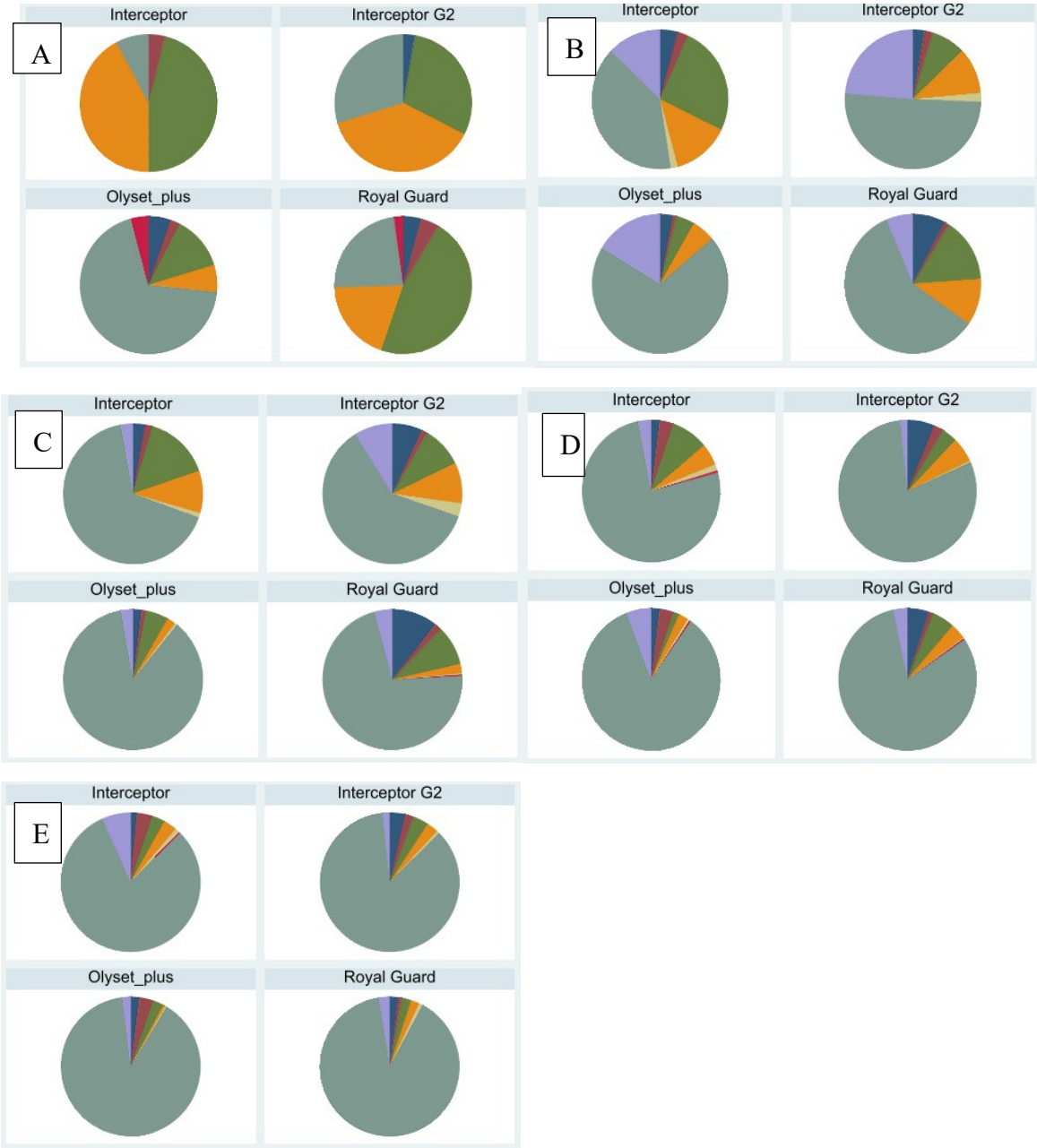
Figure 3. All causes of attrition by net type per survey. 6 (A), 12 (B)-, 24 (C)-, 30 (D)- and 36 (E)-months post-distribution.

Physical integrity

At six months, over 90% of nets distributed were still in serviceable condition except for Olyset™ Plus with 75%. These proportion decreased with time, with only 39% (95% CI: 35 – 44) of Olyset™ Plus in moderate or good condition at 12 months compared to 80% (95% CI 76 -83) for control nets (Interceptor®). Of the different dual-AI LLINs, Olyset™ Plus performed the poorest; 82% (95% CI: 74 – 88) and were categorized as too torn 36 months post-distribution, compared to Interceptor® net 52% (95% CI: 46 – 58); while 58% (95% CI: 51 – 63) of Interceptor® G2 and 68% (95% CI: 61– 74) of Royal Guard® were too torn (Figure 4).

The proportion of nets with at least one hole increased yearly (appendix 4) up to 24 months but was consistent between 30 and 36 months. There was a significant difference in proportion of standard Interceptor® with at least one hole and Olyset™ Plus (OR: 1.5, 95% CI: 1.2 – 1.8, p<0.001) at 6 months and at 12 months (OR: 1.3, 95% CI: 1.1 – 1.6, p=0.002). For Royal Guard®, the proportion of nets with at least one hole was significant at 6 months (OR: 0.7, 95% CI: 0.6 – 0.9, p=0.010) compared to Interceptor®. No significant differences in proportion of holes were observed between Interceptor® and Interceptor® G2 at any timepoint.
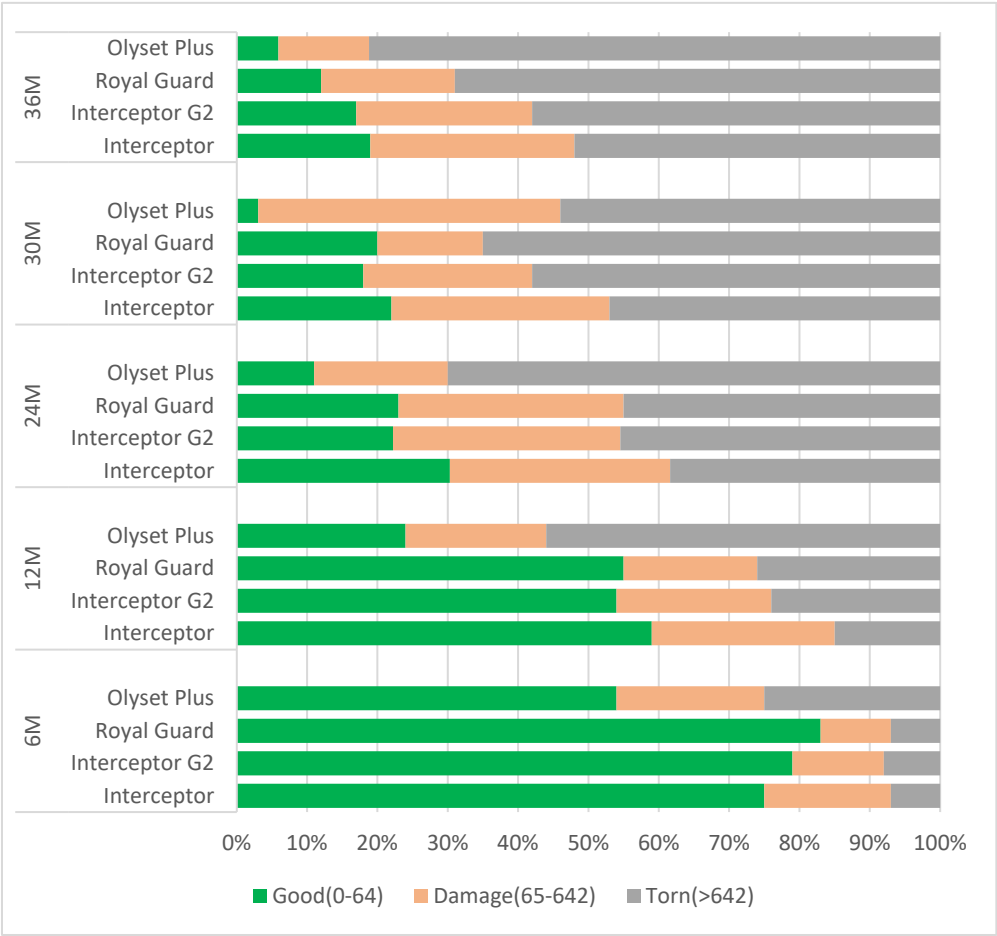

Figure 4. Physical condition of nets remaining in the household at the time of survey. Green shows proportion of nets in good condition (pHI 0-64), light pink shows proportion of nets in damaged condition (pHI 65 – 642) and grey shows proportion of nets in torn condition (pHI>643).

Function survival and survivorship of the assessed LLIN

The median functional survival for Interceptor®, Interceptor® G2 and Royal Guard® was 1.9 years each, while for Olyset™ Plus the median functional survival was 0.9 years (see Table 3). More than 80% of the study LLIN were still in the houses (survivorship) regardless of size of hole after 6 months of use and the proportion of suvivorship decreased as net age with 37% survivorship for Interceptor®

G2, 18% for Royal Guard® and 10 % for Olyset™ Plus compared to 37% for Interceptor® net after 36 months of use (see appendix 3a).

After 3 years of net use only 21.8% (95% CI: 19 – 25) of Interceptor® nets were still in serviceable condition compared to 19.7% (95% CI: 16 – 23) for Interceptor® G2, 3.9% (95% CI: 3 –6) for Olyset™ Plus and 8.6% (95% CI: 7 – 11) for Royal Guard® (see Figure 5, appendix 3b).

Table 3. Median survivorship and functional survival of surveyed LLIN.

Net type	Median survivorship with 95% CI	Median functional survival with 95% CI
Interceptor®	2.4 [2.4 - 2.7]	1.9 [1.9 - 2.0]
Interceptor® G2	2.4 [2.4 - 2.5]	1.9 [1.9 - 1.9]
Olyset™ Plus	1.9 [1.8 - 1.9]	0.9 [0.9 - 1.0]
Royal Guard®	1.9 [1.9 - 2.4]	1.9 [1.9 -1.9]
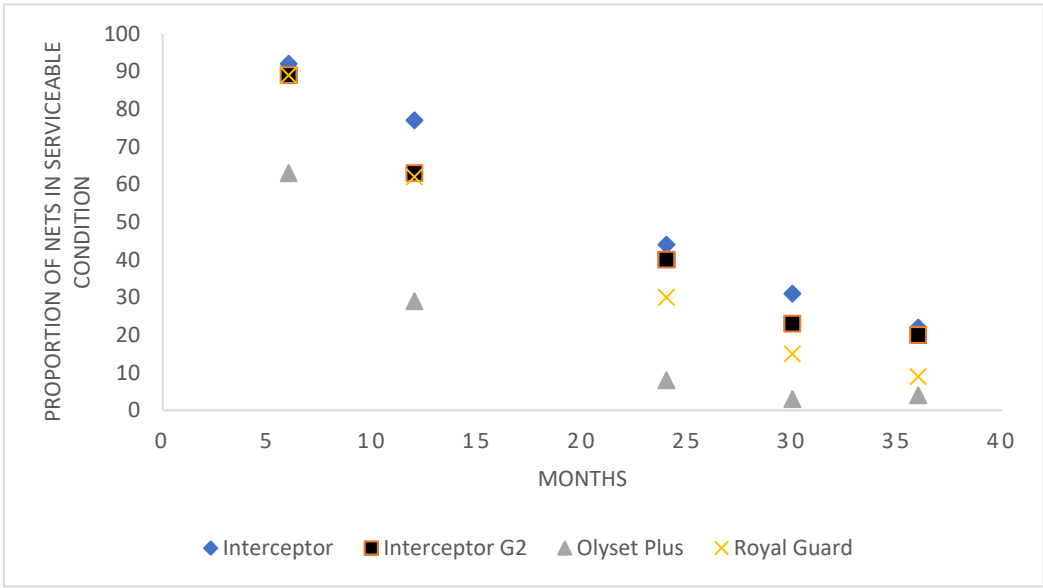
Figure 5. Estimated percentage of functionally surviving LLIN per time point.

4. Discussion

This study evaluated the fabric integrity and survivorship of dual-AI LLINs in Misungwi district, Tanzania. The study reports net life spans for functionally surviving nets which are against the WHO recommended threshold of three years in operational settings and this was observed in all four LLIN brands (1.9 for Interceptor® , Interceptor® G2 and Royal Guard® respectively and 0.9 for Olyset™ Plus) assessed and the same short life span was observed in survivorship (all net observed in household regardless of hole size) of which Interceptor® and Interceptor® G2 had 2.4 years each while Olyset™ Plus and Royal Guard® had 1.9 years each. The reasons for shorter function survival were assessed, with attrition (net thrown away) being the major cause. Physical integrity negatively impacted the function survival of LLINs i.e., at 12 months, more than half of Olyset™ Plus were in unserviceable condition compared to pyrethroid only LLINs (Interceptor®) unlike Interceptor® G2 and Royal Guard® which had more than half of study nets in serviceable condition. The nets with large holes (too torn) were discarded by users as they were perceived to provide no protection, compared with the nets in good or damaged categories. There were no statistically significant differences in functional survival of Interceptor® G2 and Royal Guard® compared to the reference LLIN (Interceptor®), unlike Olyset™ Plus.

Overall, functional survival of all LLINs was less than 3 years. One of the important factor in functional survival was physical integrity, of which more than half of Interceptor® G2 and Royal Guard® at 24 months were still in serviceable condition; unlike Olyset™ Plus which appeared to lose

its protection at 12 months as considered extremly torn. These findings support cRCT epidemiological results (16) and phase II experimental hut trials of aged LLINs taken from the community (J.Martin unpublished). The functional survival of Olyset™ Plus in this study was less than a year (0.9) and also less than what has been reported in other settings in Tanzania (9). Several other studies reported shorter functional survival than recommended by WHO. The study done in Zanzibar reported median survival of 2.9 years in Unguja and 2.7 in Pemba after 36 months follow-up of PermaNet 2.0 vs Olyset™ net (27) and the same was observed in Ethiopia with median survival of 19 months for standard LLINs (7). In contrast, a study conducted in Nigeria reported higher functional survival rates in three area surveyed (3.0 years in Nasarawa, 4.5 years in Cross River and 4.7 years in Zamfara) and the difference between states was influenced by social economic status and housing materials, rather than netting materials (28).

After 3 years of LLIN use, Olyset™ Plus, Royal Guard® and Interceptor® G2 had generally slightly higher attrition rates compared to standard LLIN Interceptor®. The questionnaire assessing all causes of attrition reported that the majority of LLINs being thrown away after 36 months of operational use were due to wear and tear and this was the leading cause of attrition. Similar finding was reported in Senegal with Interceptor® nets having less functional survival due to wear and tear (29). In the component of LLIN protection, the household reported that LLIN that was not in possession during survey were regarded as of no protection due to big hole hence thrown away (29). Some of the LLINs (Interceptor®, Interceptor® G2 and Royal Guard®) were used in other locations or given away to relatives at 36 months of age but this was not the case for Olyset™ Plus at the same timepoint. LLINs sold, stolen, destroyed accidentally and given away to others each represented a small proportion, compared to other cause of net loss.

The physical integrity of all distributed LLINs deteriorate with time, with Olyset™ Plus being the worst (82% were extremely torn) after 36 months of operational use unlike other dual AI-LLIN brands (Interceptor® G2 58%, Royal Guard® 68%) compared to Interceptor® (52%) regardless of having similar number of people sleeping under the nets, housing structures, number of sleeping places, education level and age categories. In all surveys, Interceptor® G2 had less proportion of too torn, compared to Olyset™ Plus, which was comparable to another study conducted in Tanzania, investigating fabric strength and residual bio-efficacy of both net types (30). In this study, social economic status were similar across LLIN intervention arms. The finding in the current study were different with the previous study conducted in Muleba Tanzania in spite of same denier and fiber. All factors associated with physical damage in this current study (bed frame, mattress, use of open flame, if net was ever washed, scrubbed and drying) were assessed and no association of these factors with physical damage of LLINs was observed.

5. Conclusion

The median functional survival of all LLINs assessed was less than three years (1.9 for Interceptor®, Interceptor® G2 and Royal Guard® respectively and 0.9 for Olyset™ Plus)and the main factor associated with shorter lifespan was fabric material of the net. This study found that nets lose their protection mainly because of wear and tear which is related to the physical integrity of the net. Interceptor® G2 were found to have better fabric material unlike Olyset™ Plus and was close similar to Royal Guard®.

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