Modes of physical deterioration of LLINs in different settings

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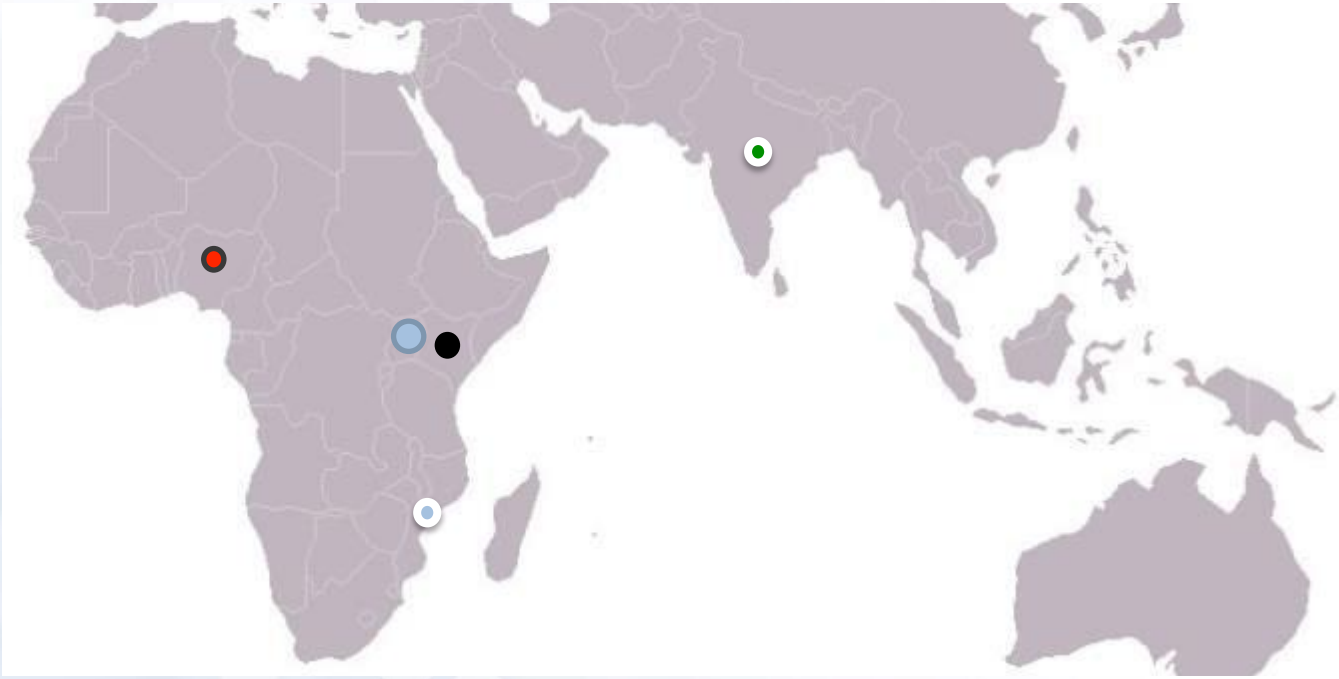
Aims

- To understand the **actual causes and modes of physical deterioration** of LLINs in field settings.

- To lay a foundation for improved LLIN **textile testing methodology** that can be used in LLIN procurement and to encourage innovation in net technology.

LLINs were Retrieved from the Field in Africa and Asia by Tropical Health LLP



- Nigeria: CDC/PMI;

  3 separate locations within Nigeria.
- Kenya: CDC
- Uganda: Tropical Health LLP
- Mozambique: PMI
- India: WHOPES

- Total LLINs analysed: 526.
- Periods of use: 12, 18 and 36 months.
- LLIN types: PermaNet, Olyset, Dawaplus, Duranet, Interceptor, and Net Protect.

Analysis of all individual defects in LLINs

- Direct analysis to determine damage mechanisms resulting from use in the field.
- Multi-scale approach: individual areas of damage were visually inspected assisted by optical microscopy and Scanning Electron Microscopy (SEM).
- > 41,294 individual damage sites inspected.
- Inspection of entire LLIN structure.

Overall Profile of Structural Damage in LLINs

Results based upon 41,294 individually inspected sites of net damage.

Damage

Imperfections observed in a net that would not be present in an unused net encompassing : holes, pulls and all other defects.

57.2 %

Pulls

A structural imperfection in the fabric caused by a snagging action but not resulting in a broken yarn. Yarns in the fabric structure are displaced (pulled) resulting in a visible loop on the surface.

41.3 %

Holes

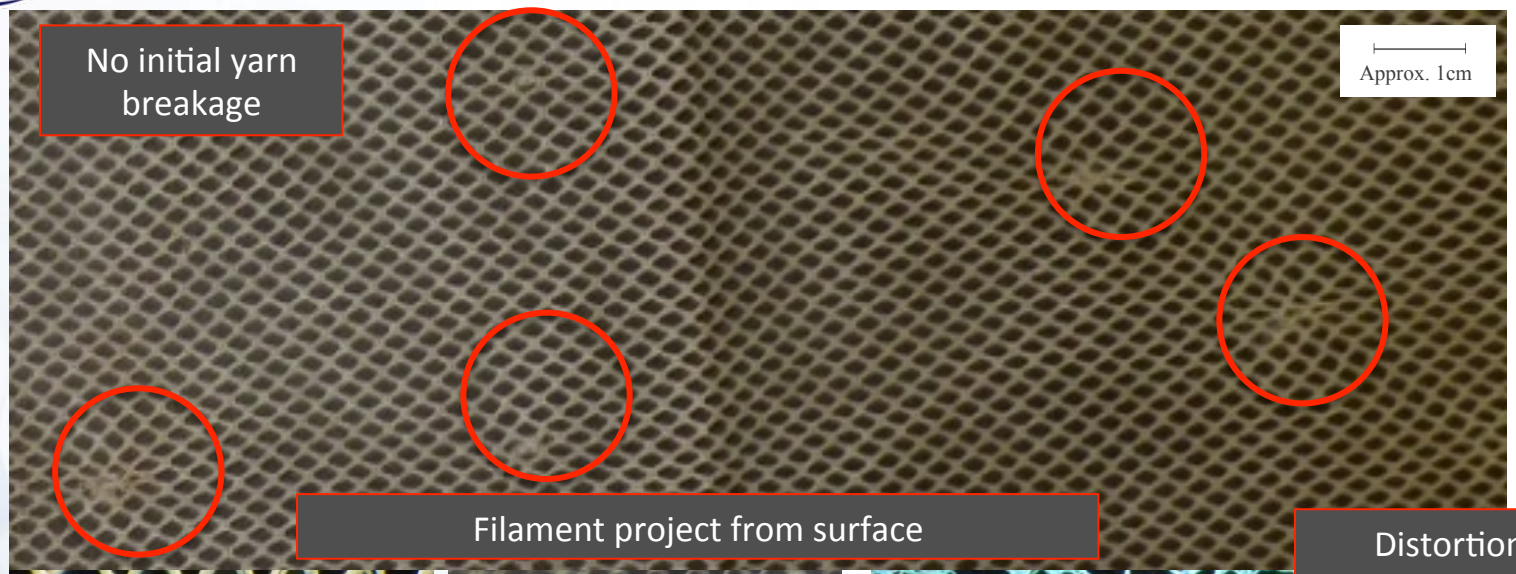
A discontinuity in the fabric structure that results in an opening greater in diameter than that associated with the mesh structure.

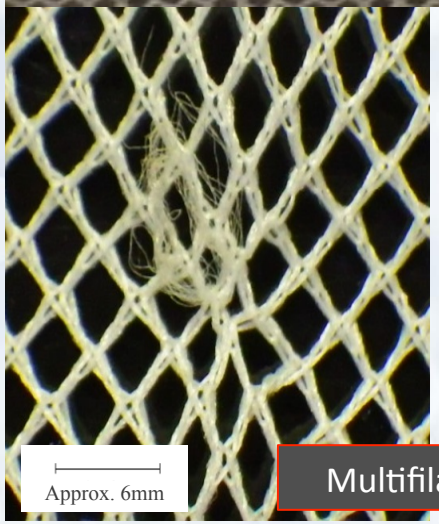
1.5 %

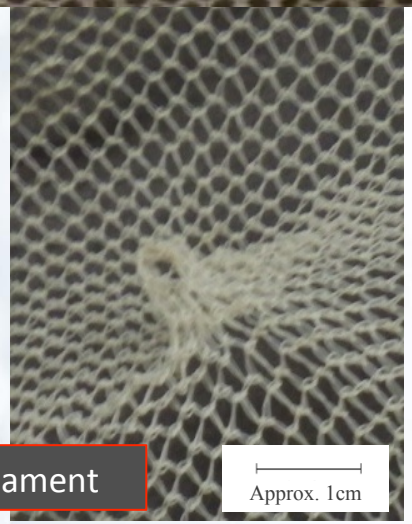
Other Defects

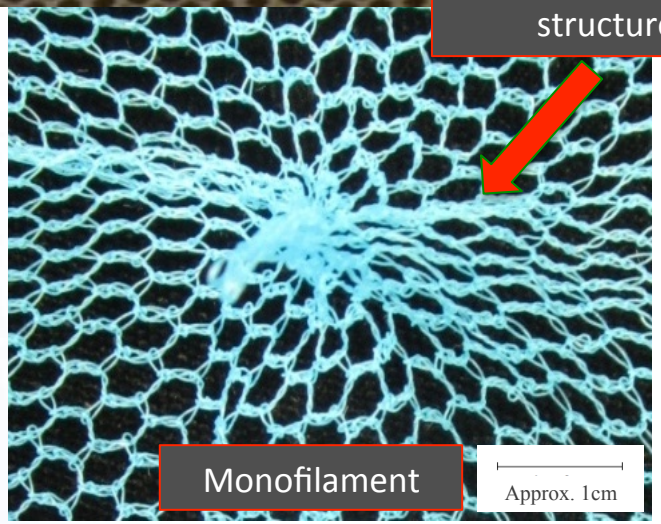
All other imperfections that would not be present in the unused net but which do not result in either a hole or a pull.

Pull Damage (net snags on a rigid protuberance)

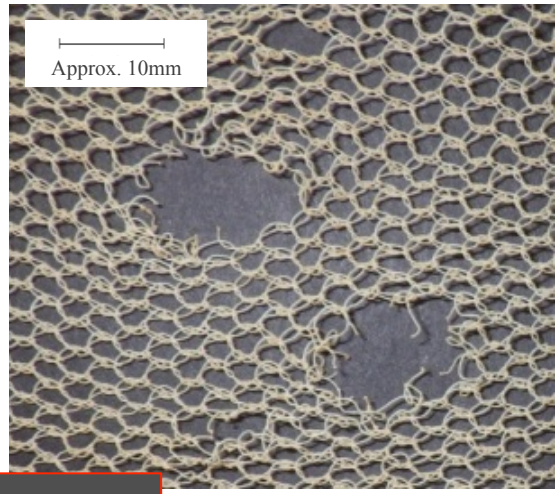




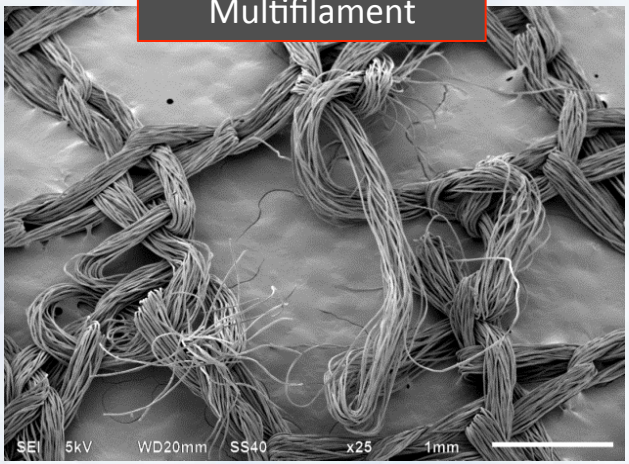




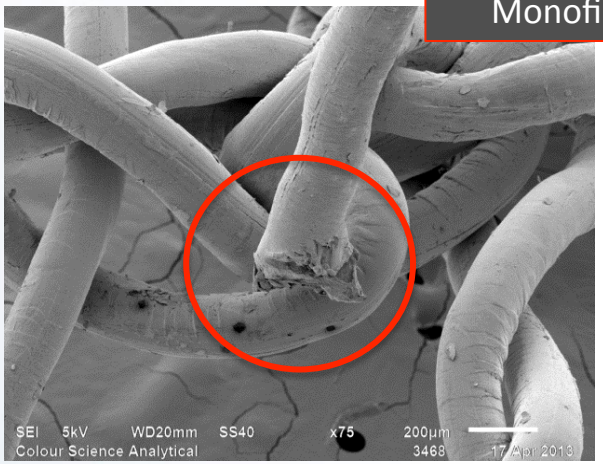
Snag Hole Damage

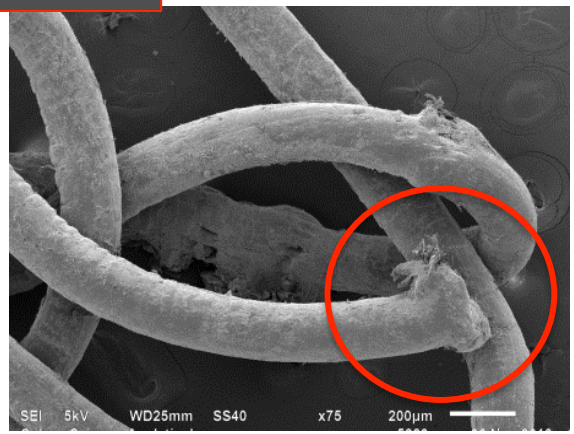


Multifilament

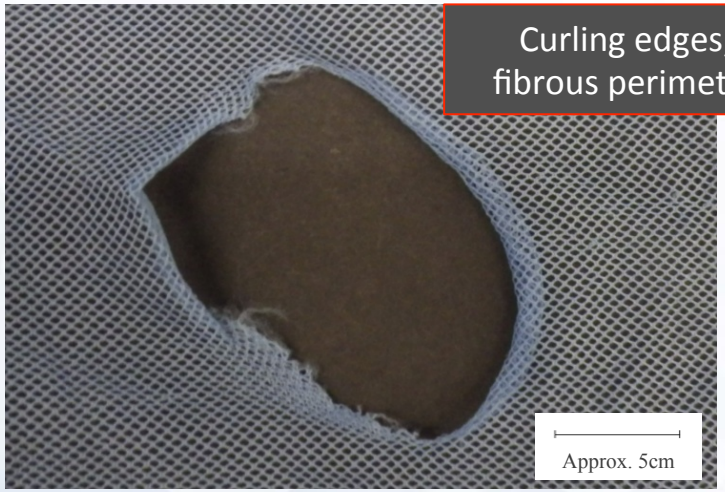


Monofilament

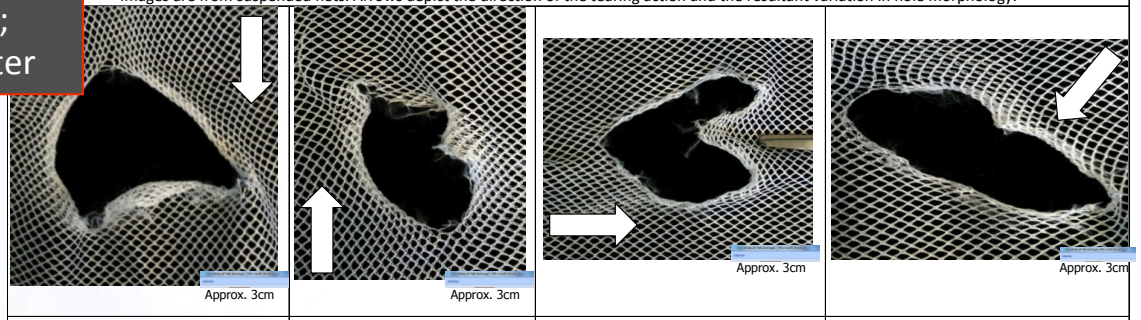




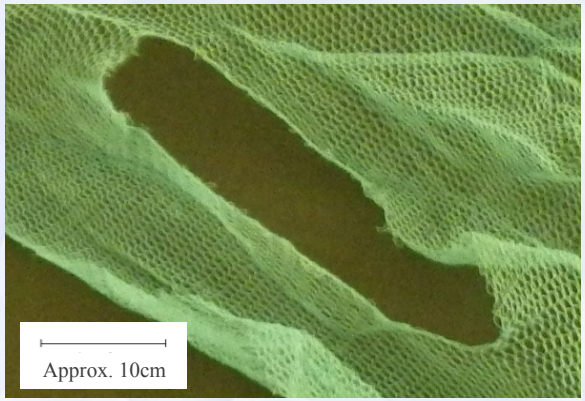
Tear Hole Damage

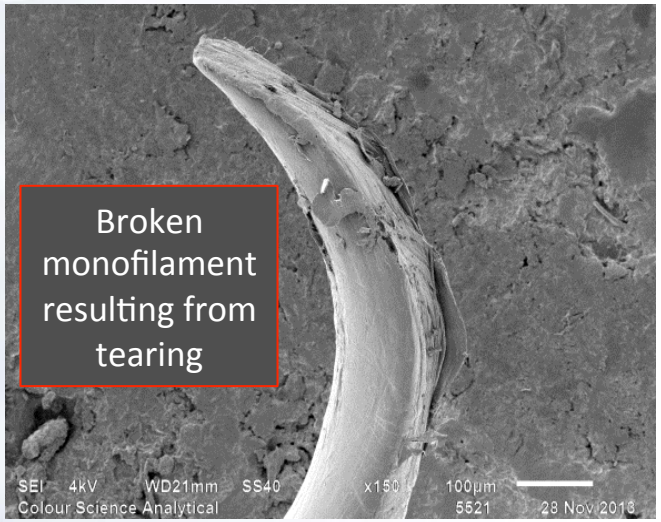


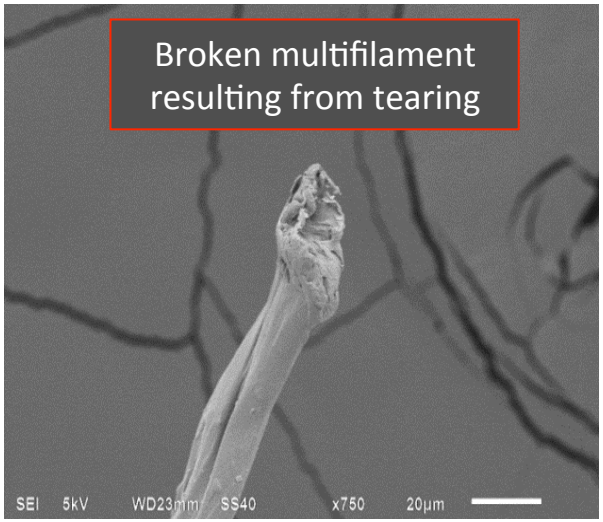
Images are from suspended nets. Arrows depict the direction of the tearing action and the resultant variation in hole morphology.



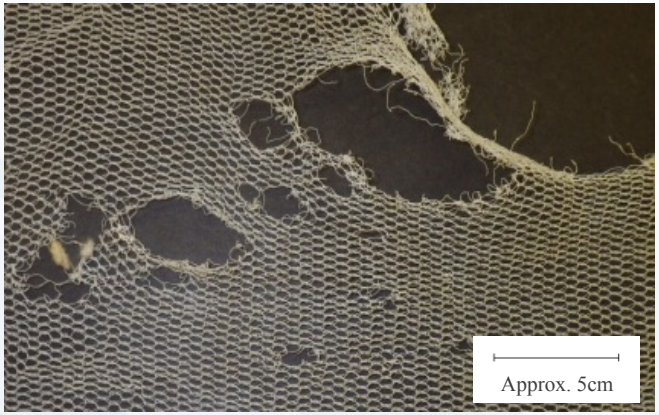
Macro image. Force applied in the downward direction. Distinct triangular shaped hole. No distortion around hole.	**Macro image. Force applied in the upward direction.**	**Macro image. Force applied in crosswise direction. Triangular like shape. The 'peak' area on the right hand side corresponds roughly to the size of the blunt instrument.**	**Macro image. Force applied in the diagonal direction.**



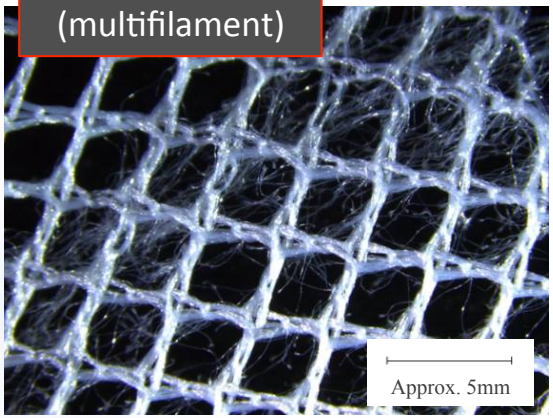




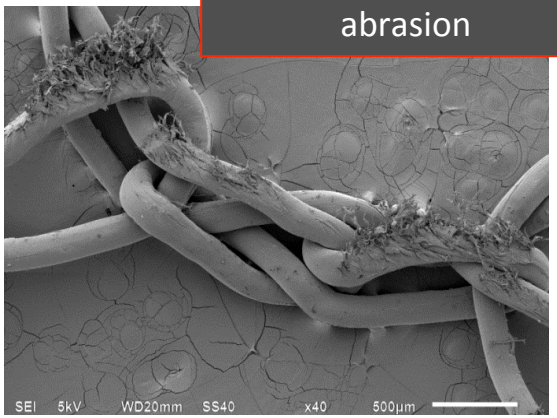
Abrasion Hole Damage



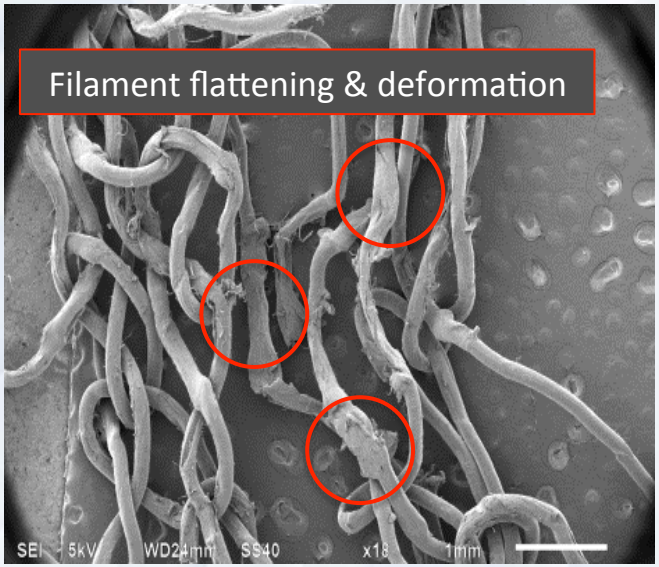
Surface "fuzz" (multifilament)



Monofilament, surface abrasion

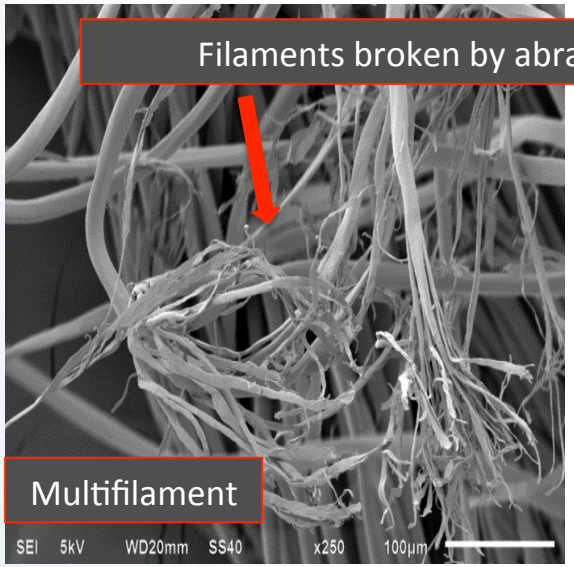


Filament flattening & deformation

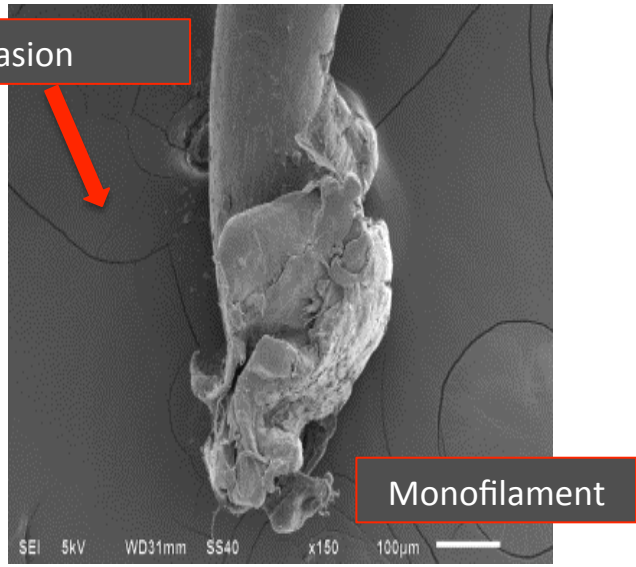


Filaments broken by abrasion

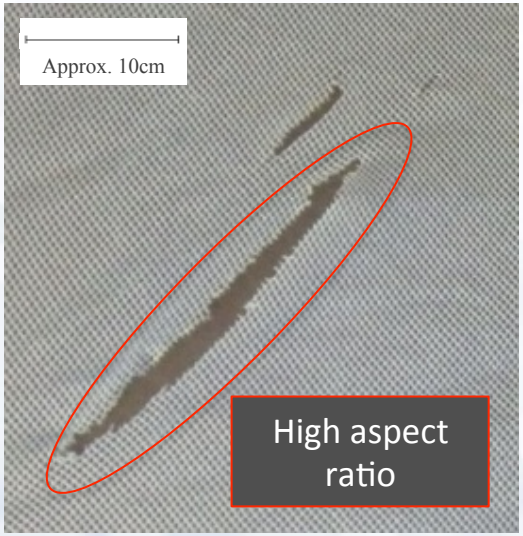
Multifilament

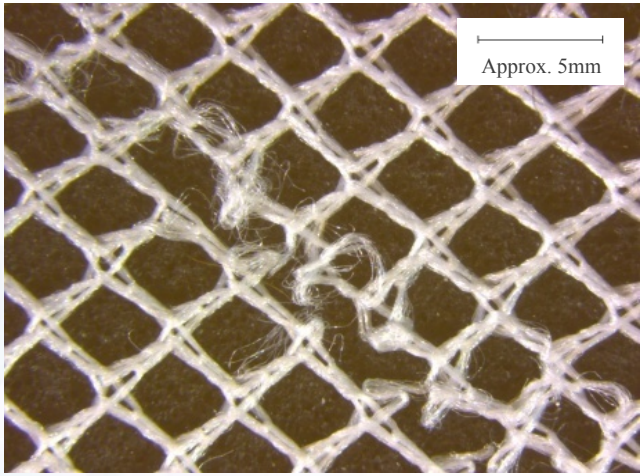


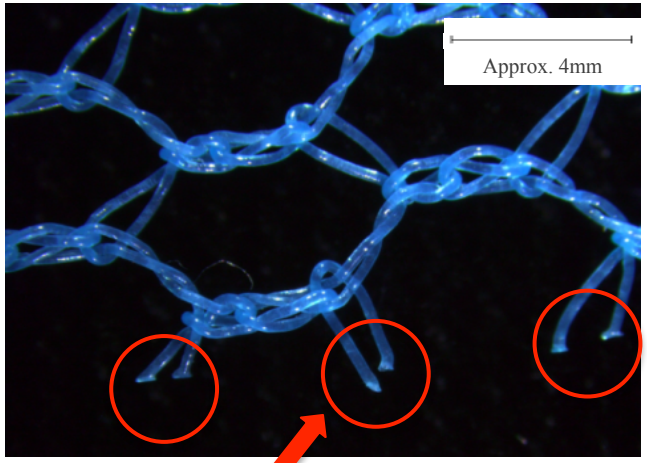
Monofilament

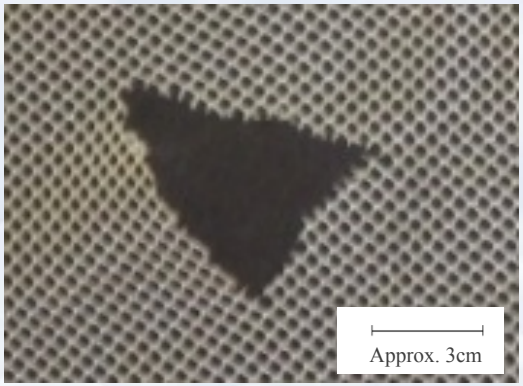


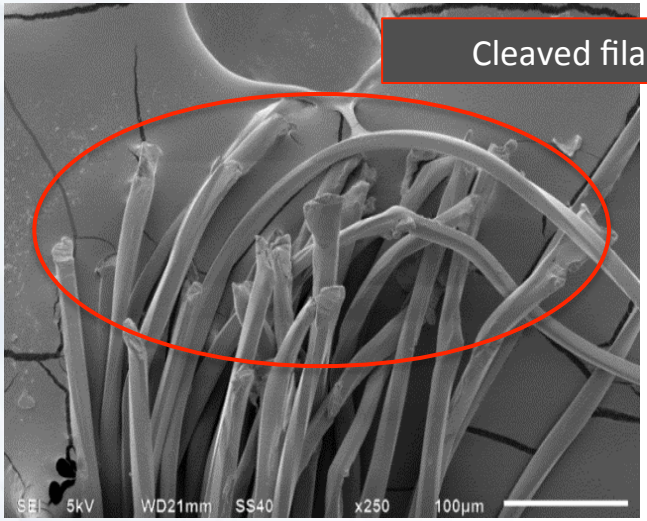
Cut Hole Damage



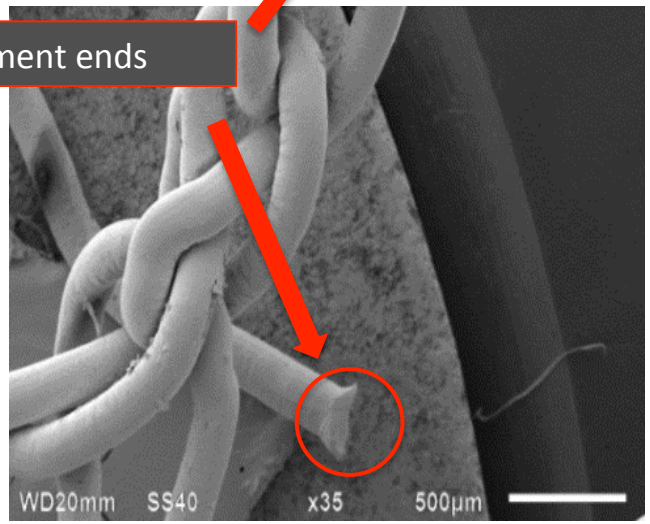




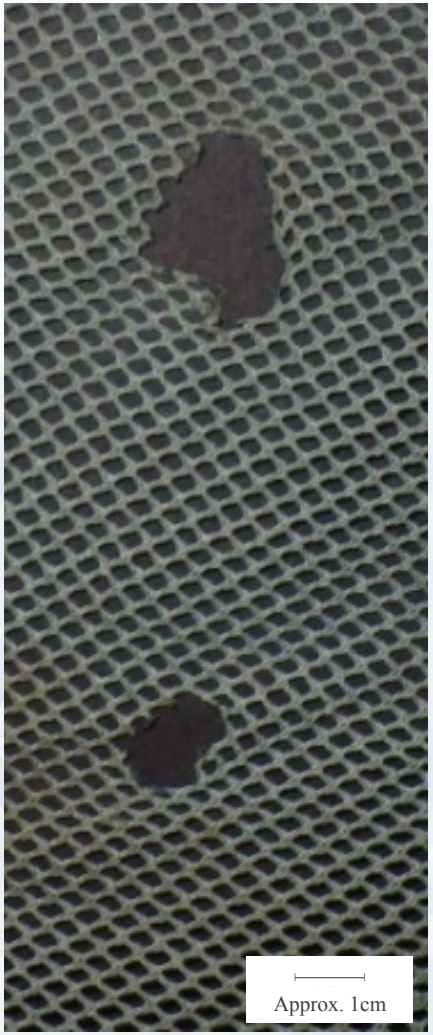


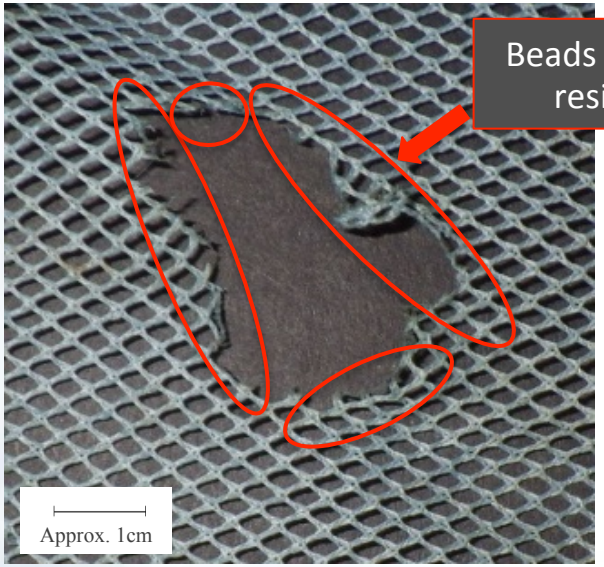


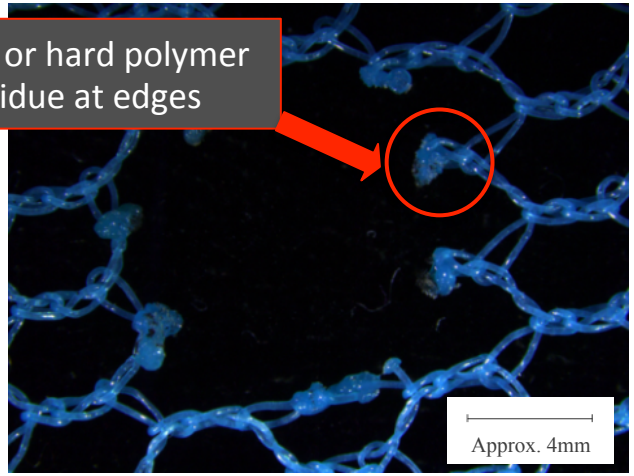
Cleaved filament ends

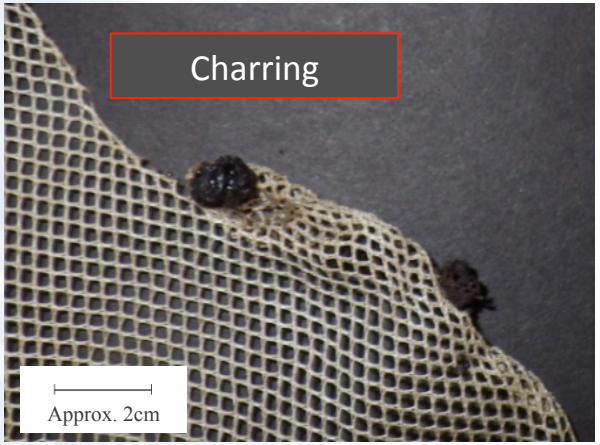


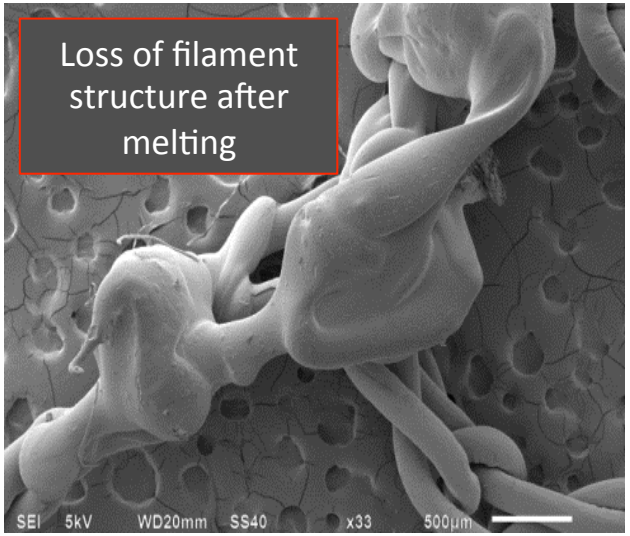
Thermal Hole Damage



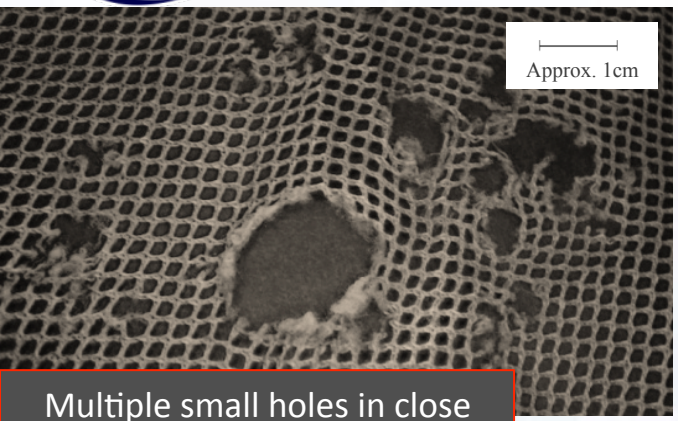




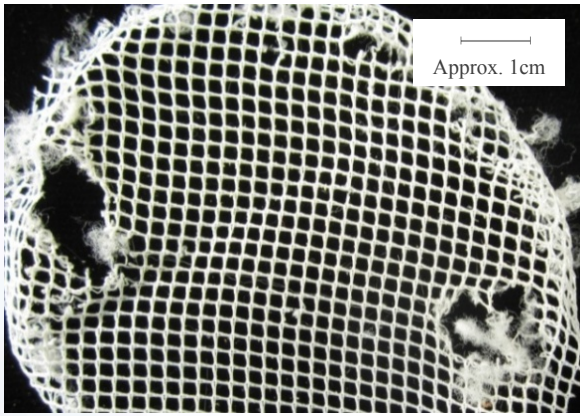


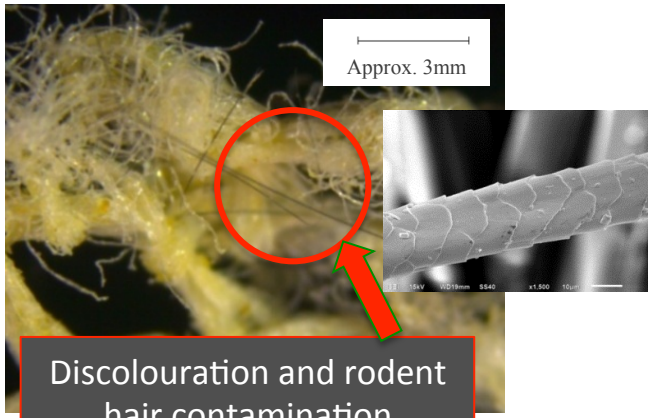


Rodent Hole Damage

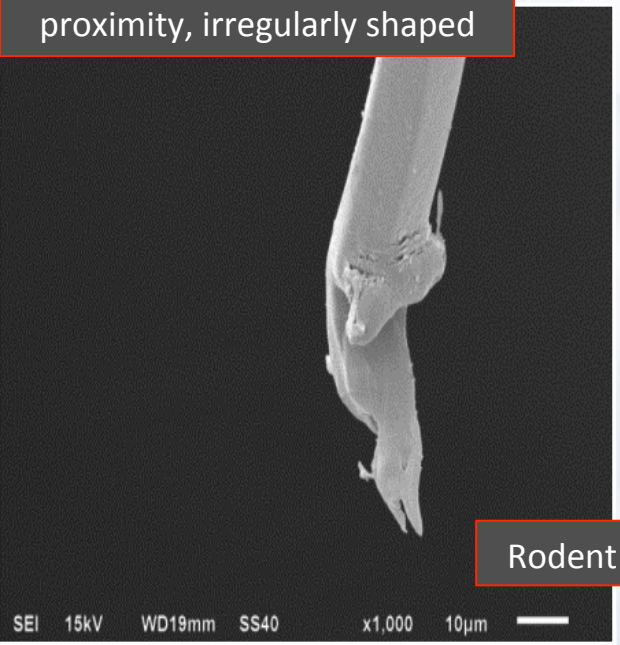


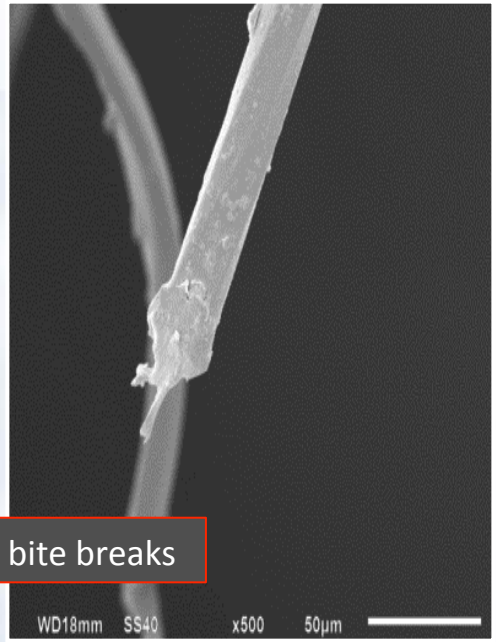
Multiple small holes in close proximity, irregularly shaped



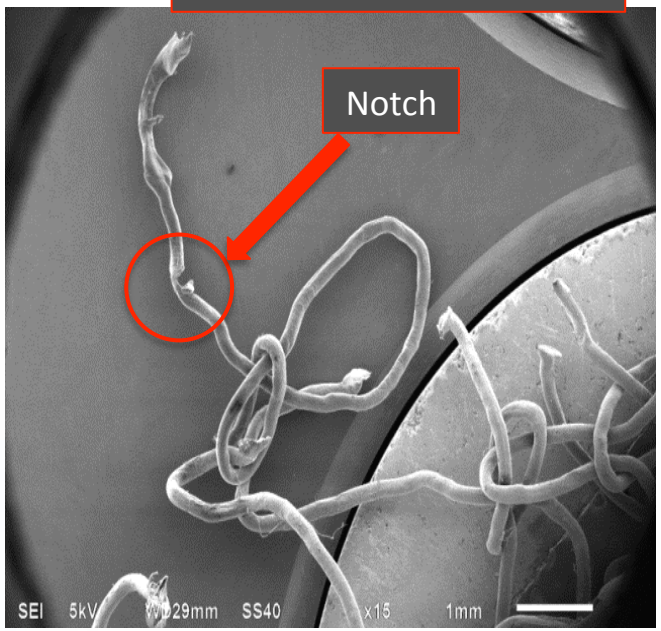


Discolouration and rodent hair contamination



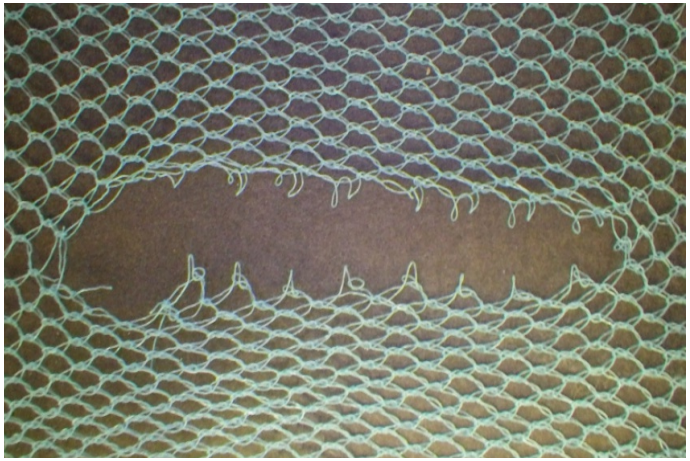


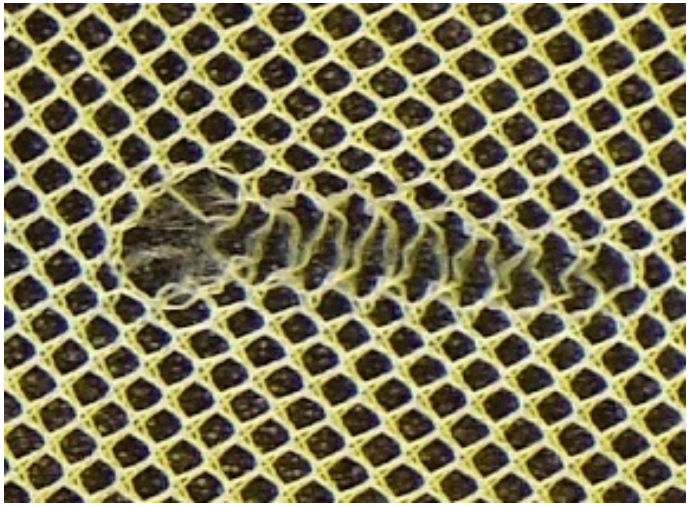
Rodent bite breaks



Secondary Damage

- Primary damage can seed larger holes as a result of unravelling and laddering.
- The degree of secondary damage is influenced by factors such as the selection of the knitted fabric structure.



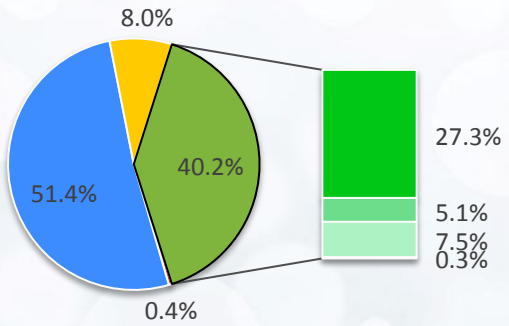


Seven primary mechanisms leading to holes

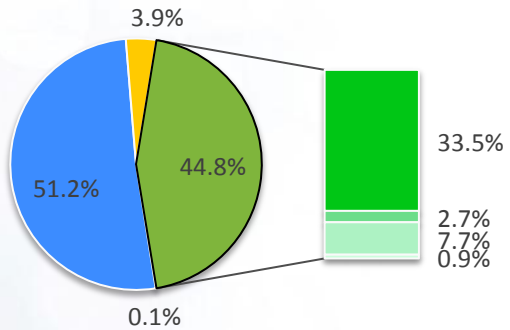
	Classes of Damage	
	Primary (Initiation)	
Mechanical	**Snag**	Yarn or part of a yarn pulled or plucked from the surface.
Mechanical	**Tear**	Tensile failure of yarns within the fabric plane in for example two opposing directions.
Mechanical	**Abrasion**	The wearing away of any part of a material by rubbing against another surface.
Mechanical	**Cut**	Yarn that is failed by slicing with a sharp object.
Thermal	**Thermal**	Polymer that is exposed to temperatures high enough to cause shrinkage, plastic flow or degradation and failure of the yarn.
Rodent/Animal	**Rodent/Animal damage**	Damage caused by gnawing of indigenous rodents, chewing of domestic animals or interaction with birds.
Other	**Seam Failure**	Effective breakdown of a seam due to rupture of the sewing thread or yarns in the fabric, excessive seam slippage or any combination of these.
	Secondary (Propagation)	
	Laddering	Pulling out of successive knitted loops in a wale, leaving straight segments of yarns.
	Unravelling	Following yarn failure, the broken yarns allow the loops of the knit structure to un-loop creating a larger hole.
	Tearing	Tensile failure of yarns within the fabric plane in for example, two opposing directions after primary damage has been initiated.

Damage mechanism profiles in LLINs (by hole frequency)

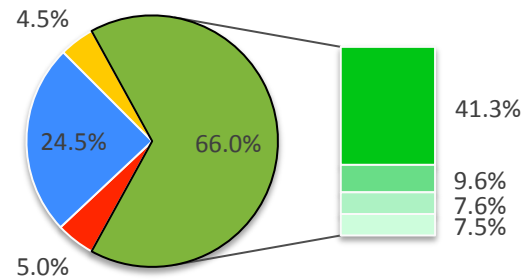
Mozambique



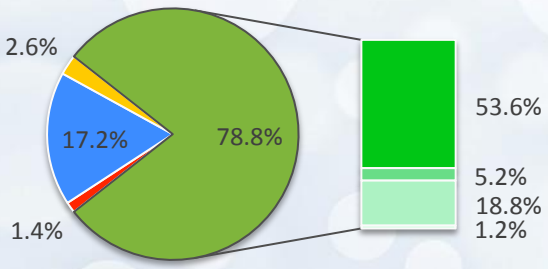
Nigeria Region 1



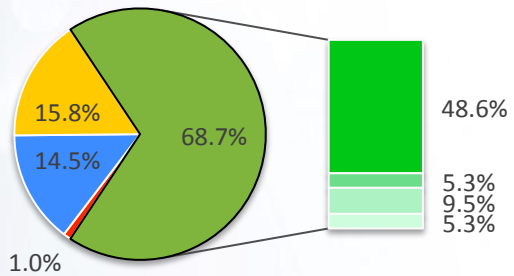
Nigeria Region 2



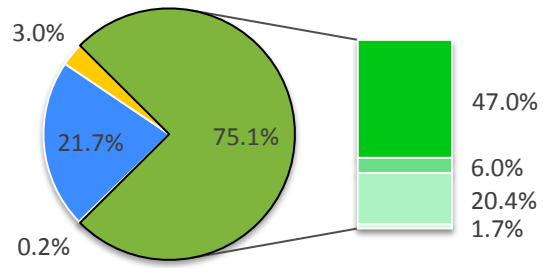
Nigeria Region 3



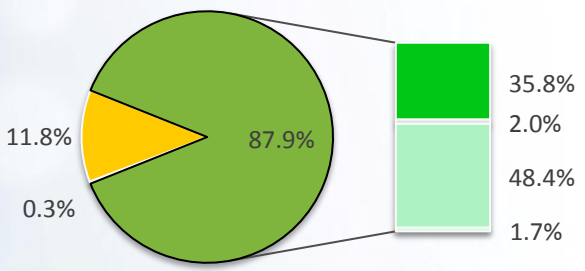
Kenya



Uganda



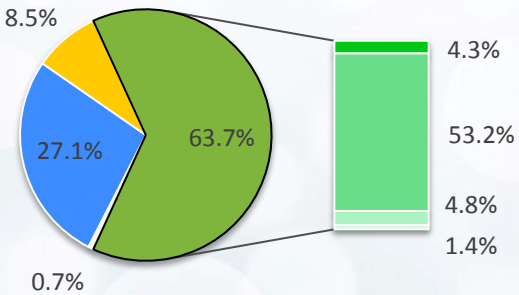
India



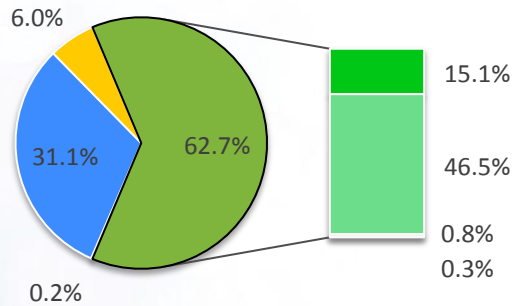
- Mechnical
- Thermal
- Rodent
- Seam Failure
- Snag
- Tear
- Abrasion
- Cut

Damage mechanism profiles in LLINs (by hole area)

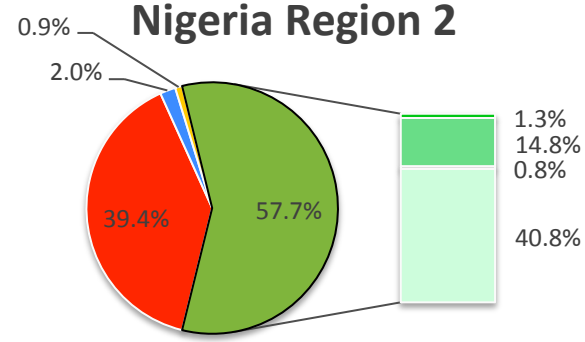
Mozambique



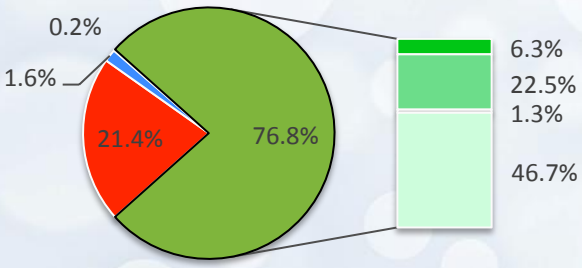
Nigeria Region 1



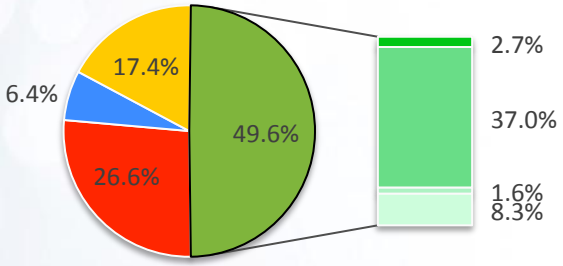
Nigeria Region 2



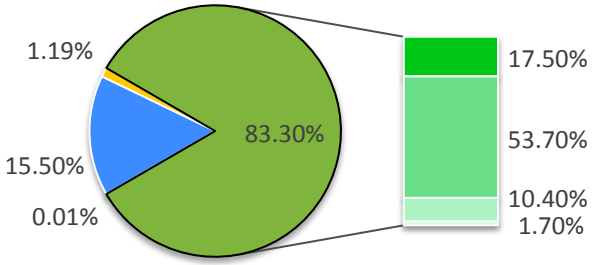
Nigeria Region 3



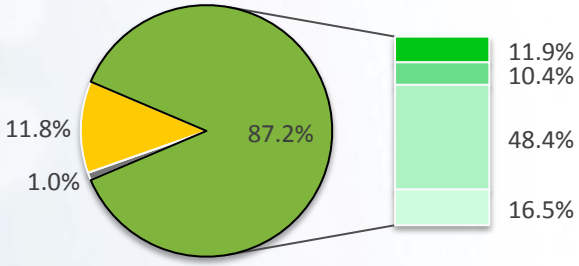
Kenya



Uganda



India



- Mechnical
- Thermal
- Rodent
- Seam Failure
- Snag
- Tear
- Abrasion
- Cut

Influence of damage mechanism on hole size

Damage mechanism	Median hole size (cm)							Small Medium Large
	Mozambique	India	Nigeria R1	Nigeria R2	Nigeria R3	Kenya	Uganda	
Snag	1	1	0.5	0.5	0.5	1	1	≤ 1 cm
Tear	5	8.5	4	5	4	5	7	4 – 8.5 cm
Abrasion	2	1	0.5	0.5	0.5	1	1.5	1 - 2 cm
Cut	6	5	5	3	2	1	1.5	1 - 6 cm
Thermal	1.5	1	0.5	1.5	1	1.5	1.5	≤ 1.5 cm
Rodent	1	-	0.5	1	0.5	1	1.5	≤ 1.5 cm
Seam	6	7	4.5	10	2.5	5.5	1.5	1.5 -10 cm

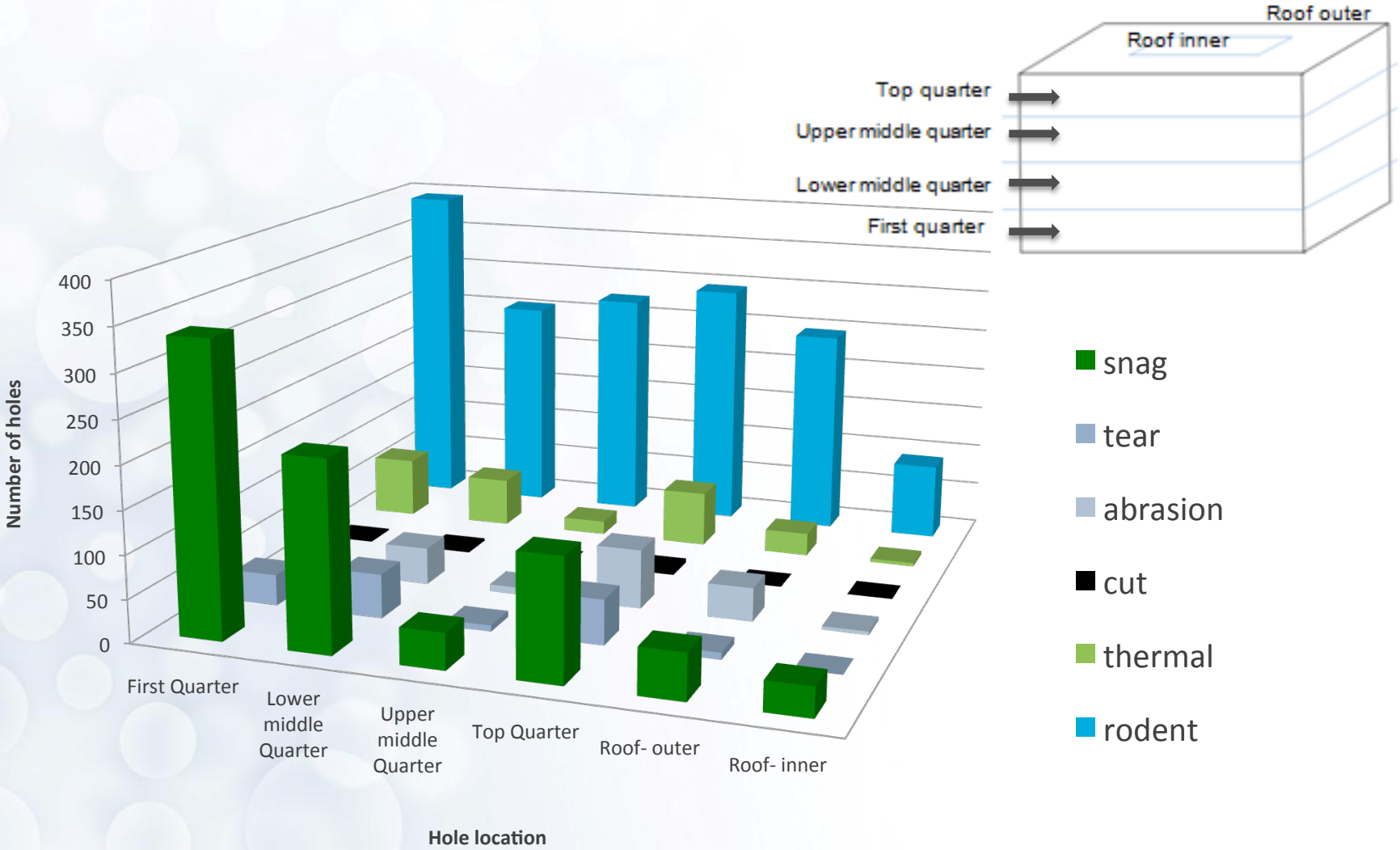
- Tearing and seam failure produce the largest holes.
- Abrasion and cutting produce holes of intermediate size.
- Snagging and rodent damage produce numerous small holes.

Proportion of LLINs in each location found to contain holes by individual damage mechanism

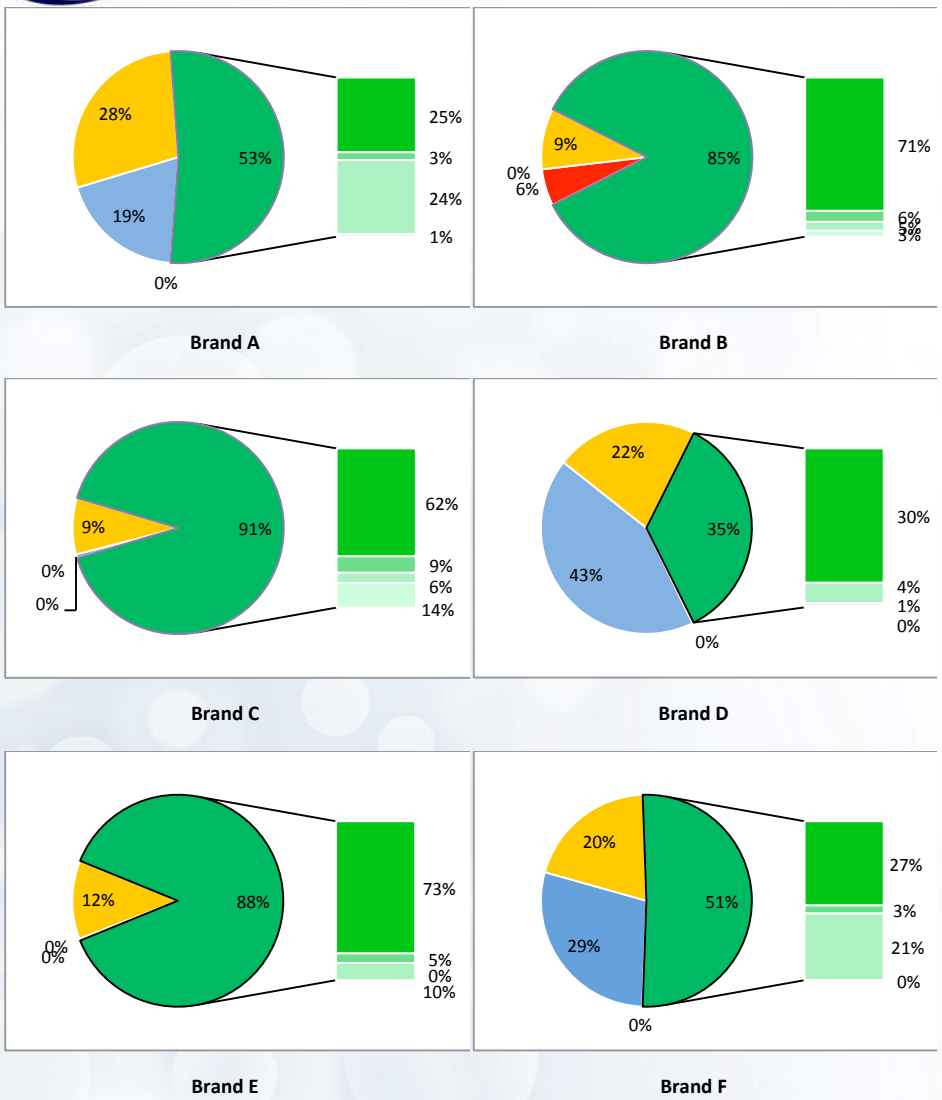
Damage mechanism	Nets affected (%)							
	Mozambique	Nigeria R1	Nigeria R2	Nigeria R3	Kenya	Uganda	India[I]	India[II]
Snag	98	91.7	94.3	100	83.7	97	30	61.1
Tear	61	54.2	60	67.6	49.5	70	4.5	9.3
Abrasion	41	20.8	14.3	11.8	15.3	51	19.1	38.9
Cut	9	37.5	57.1	23.5	12.9	11	2.7	5.6
Thermal	61	50	34.3	17.6	68.3	30	16.4	33.3
Rodent	27	50	11.4	5.9	7.9	13	0	1.9
Seam	9	8.3	45.7	26.5	12.9	5	0.9	61.1

India[I] - sample including nets with no holes (110 nets).
India[II] sample excluding nets with no holes (54 nets).

Example of the distribution of holes in LLINs (Mozambique) by damage mechanism



Hole damage profiles in different LLINs (Kenya)



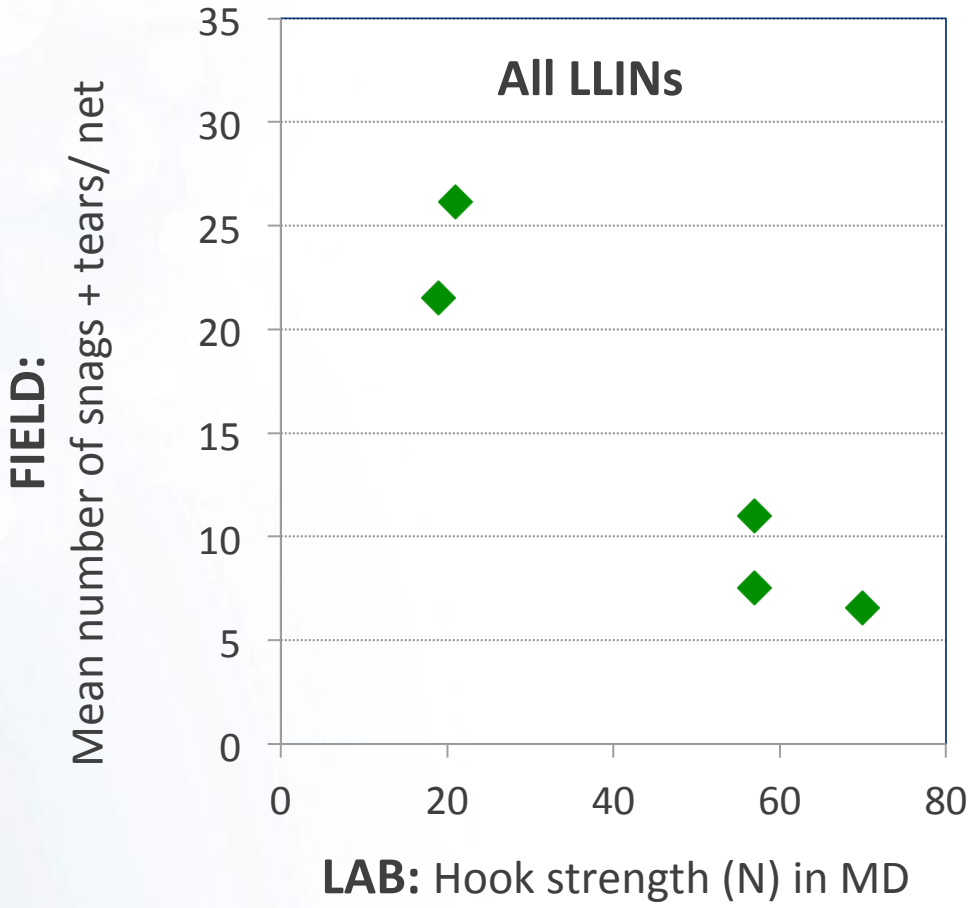
Mechnical
Thermal
Rodent
Seam Failure
Snag
Tear
Abrasion
Cut

- Snagging and tearing are consistent contributors to hole formation and are likely to be related to LLIN structure.
- Thermal, cut and rodent hole damage may reflect user habits.

Time in use for all: 18-24 months

Relationship between mechanical damage in the field & lab data (Kenya)

Preliminary data suggest LLIN hook strength and mechanical hole damage (snag and tear) may be related.



Summary

- During use LLINs accumulate a "damage profile" with up to seven different sources of primary hole formation. All seven can be present in one net.
- Mechanical damage is the most widespread and persistent source of holes across seven different study sites and five different countries. Rodent damage is also a major contributor.
- Improving snag resistance (reducing the probability of snagging) is likely to result in better durability.
- Currently, LLINs are particularly susceptible to holes due to cutting, thermal and rodent damage.