DETERMINATION OF FABRIC STRENGTH OF LONG-LASTING INSECTICIDAL NETS

REPORT OF A WHO CONSULTATION
GENEVA, 20–22 AUGUST 2014

CONTROL OF NEGLECTED TROPICAL DISEASES
WHO PESTICIDE EVALUATION SCHEME

AND

GLOBAL MALARIA PROGRAMME

World Health Organization

Printed in France.

WHO/HTM/NTD/WHOPES/2015.1

CONTENTS

1. INTRODUCTION

A WHO consultation on assessment of the strength and durability of fabric for long-lasting insecticidal nets (LLINs) was convened at WHO headquarters, Geneva, Switzerland, on 20–22 August 2014. The meeting was convened in open and closed plenary sessions. The open meeting was attended by representatives of industry, institutional observers, including the Bill & Melinda Gates Foundation, the Global Fund to Fight AIDS, Tuberculosis and Malaria and Research for Development (R4D), in addition to members of the expert advisory group and the WHO secretariat. Annex 1 contains the agenda and Annex 2 the list of participants. The closed meeting was restricted to WHO experts and secretariat.

The consultation was opened by Dr John Reeder, Acting Director, Global Malaria Programme, who welcomed participants and noted that the WHO study on determining the fabric strength of LLINs was another successful collaboration between the WHO Global Malaria Programme and the Department of Control of Neglected Tropical Diseases. Dr Reeder thanked individual participants, countries, programmes and institutions for their contributions, noting that LLIN manufacturers had provided net samples and agreed to share the results of the study. He also thanked the Centro Tecnológico das Indústrias Têxtil e do Vestuário (Portugal) for conducting textile tests on LLINs and Dr Stephen Smith (Centers for Disease Control and Prevention, USA) for writing the study report. The Global Fund deserved special recognition for providing the resources to support this critical study on laboratory assessment of LLIN fabrics. WHO has recognized for some time that additional parameters of fabric strength should be included in WHO specifications of LLINs for quality control. A WHO position statement in 2011 noted that the cost per year of effective protection rather than the cost per LLIN should be considered. The present consultation would review the data from the two phases of the LLIN study: an initial data generation phase and a second phase on "wounded bursting strength" of LLINs, as requested by the expert group at the previous consultation in August 2013. The data will be used to improve the minimum specifications of LLINs and stimulate improvements in their quality and innovation. Dr Reeder highlighted the question to be addressed by the group: Are these data a sufficient basis for guidance on procurement? He asked the expert panel to recommend to WHO the way forward in obtaining data on the durability of LLINs under operational conditions and using the data to make recommendations, as had been done for rapid diagnostic tests for malaria. He looked forward to the conclusions and recommendations of this important consultation.

Dr Raman Velayudhan, Coordinator, Department of Control of Neglected Tropical Diseases/Vector Ecology and Management, welcomed participants and outlined the administrative arrangements for the meeting. Dr John Gimnig was appointed Chairman and Dr Stephen Smith as Rapporteur.

Dr Abraham Mnzava, Coordinator, Vector Control Unit, Global Malaria Programme, recounted the history and challenges of the project and said that field data on net performance were required at country level.

Dr Rajpal Yadav, Scientist in Charge, WHO Pesticide Evaluation Scheme (WHOPES), described the parameters already in the WHO specifications for quality control of LLINs, including denier, netting mesh size, dimensional stability to washing and bursting strength and detailed standards and criteria for technical materials and formulations. The areas of potential importance that were not yet in the specifications include data on the storage stability, flammability and mass of netting (fabric weight).

DECLARATIONS OF INTEREST

All the invited experts completed a form of declaration of interests for WHO experts, which were submitted to and assessed by the WHO Secretariat prior to the meeting. The following interests were declared:

Dr Albert Kilian's consultancy company has received a consultancy fee for a review of the literature and a grant to support a study of the durability of various brands of LLINs from Bayer CropScience Germany.

Dr Olivier Pigeon's research centre has received prescribed standard fees from eight manufacturers of pesticide products (BASF Germany, Bayer CropScience Germany, Gharda Chemicals India, NRS International United Arab Emirates, Sumitomo Chemical Japan, Syngenta Switzerland, Tagros India and Vestergaard Frandsen Switzerland) to meet the costs of physico-chemical studies of pesticide products manufactured by the respective companies.

Professor Dr Stephen Russell's institute received a research grant from R4D for a study on mechanisms of net degradation in LLINs.

The interests declared by the experts were assessed by the WHO Secretariat. With the exception of that of Dr Albert Kilian, the declared interests were determined not to be directly related to the topics being discussed at the meeting. It was therefore decided that those experts could participate in all technical sessions of the consultation, subject to public disclosure of their interests. In view of the declared interest on the part of his consultancy company, Dr Kilian did not participate in the discussions on Bayer's LifeNet LLIN.

2. LABORATORY STUDY ON FABRIC STRENGTH OF LLINS

Dr Stephen Smith (Centers for Disease Control and Prevention) gave an overview of the results of the WHO study on the fabric strength and flammability of LLINs, tested at the Centro Tecnológico das Indústrias Têxtil e do Vestuário, Portugal. The aim of the study was to subject LLINs (11 WHOPES-recommended LLINs and three that were in phase II of WHOPES evaluation) to standard tests of textile strength and flammability and to correlate the results with available data on physical durability in the field. The study was conducted in two rounds: round 1 was completed in July 2013, and the results were discussed during the WHO technical consultation on 20–22 August 2013; round 2 included several additional tests for fabric strength and additional LLIN products.

The first consultation concluded that the results of standard tearing tests were invalid because of poor reproducibility. These tests include the ballistic pendulum (Elmendorf) test (EN ISO 13937-1), the trouser tear test (ISO 13937-2), the wing tear test (ISO 13937-3) and the tongue tear test (ISO 13937-4). It was noted that knitted fabrics (such as mosquito netting) are generally considered by the textile industry to be ill suited for testing by these methods, because of poorly reproducible tearing behaviour.

Round 1 also included testing for pneumatic bursting strength (EN ISO 13938-2), grab tensile strength (ISO 13934-2) and a non-standard modification of the tensile strength test in which hooks were used instead of clamps to attach the sample to the tester (termed the "hook tensile strength test"). Nets tested for grab tensile strength failed by rupturing at the clamp ("jaw break"), which produces invalid results according to ISO guidelines. The results of hook tensile testing correlated surprisingly well with those for bursting strength, which suggests that the standard bursting strength test may be suitable for measuring resistance to damage by snagging, which the hook tensile test was designed to simulate.
Round 1 testing did not cover all the WHOPES-recommended LLINs, as not all manufacturers submitted samples for testing. A second round of testing was therefore recommended, which would include these and several other nets not

tested in the first round, including three that were in WHOPES phase-II testing at that time. The recommended tests included bursting strength, grab tensile and hook tensile methods; tear testing was not recommended because of their poor reproducibility.

The first consultation also recommended that a modified bursting strength test be conducted on the complete set of nets in the study. This test, termed the "wounded bursting strength" test, involves a net sample with a small cut in it to measure how well the net retains its strength after minimal damage by, e.g. a rodent or a spark. The results could indicate that holes tend to enlarge after initial formation and therefore correlate with the hole sizes in nets recovered from the field. A study by the US Centers for Disease Control and Prevention and the North Carolina State University showed wide variation in the performance of LLINs tested in this way.

Round 1 also included flammability testing. Two methods were evaluated: a 45° angle test (16 CFR Part 1610) and a vertical test (EN 1102). All nets passed the 45° angle test, but a few nets propagated a flame in the vertical test, producing drips of flaming plastic. As the sides of LLINs are generally vertical when in use, the vertical test was considered by the consultation to be more realistic. Both tests were also included in round 2.

Much of the discussion at the first consultation was on establishing categories or tiers of performance for the tested nets. The results did not, however, show clear "break points" that would allow assignment of clear-cut performance categories without appearing to be arbitrary.

The results of round 2 testing, which included additional LLIN products, generally confirmed the conclusions of round 1 with respect to bursting strength, grab tensile, hook tensile and flammability testing. In the wounded burst strength test, polyethylene monofilament nets as a group lost more strength than multifilament polyester and polypropylene nets. Whether this is due to the polymer, the number of filaments, the knitting pattern or some other factor could not be determined.

The report of the full WHO study is contained in *Annex 3*.

DISCUSSION

The mandate of the meeting was to understand the causes of deterioration of LLINs and to determine whether they can be replicated through laboratory testing. High-quality studies of the durability of nets in the field, comparisons of field data with laboratory measures of net performance and linking the observed causes of damage with the laboratory and field measures of durability are all critical for validating the predictive value of LLIN laboratory tests. Current data on the durability of LLINs in the field are inadequate, variable and of poor quality. Direct prospective trials to compare different brands of net in in a variety of field settings will provide the necessary information. To obtain reliable data for evaluating net durability in the field, data collection methods should be standardized, taking advantage of pool procurement so that different brands are distributed to the same areas and are labelled appropriately. Netting pattern, fabric weight, type of fabric and hole location may all contribute differently to both net performance in laboratory tests and their durability in the field. Understanding the relative contributions of different factors could inform the design of more durable nets and criteria for targeting nets to appropriate settings.

Field data are also needed to determine value for money. With sufficient information on the use and misuse of nets, the causes of damage could be linked to net performance in selected laboratory tests (e.g. hook versus bursting strength), thus strengthening their predictive value. Procurement agents require means to distinguish among products and decide which nets are most suitable for different situations. The value of this information for procurement could therefore outweigh the costs of collecting it.

Changing the pricing of nets from price per unit to a pricing structure that reflects the cost over the lifetime of the net could encourage innovative products. Procurement agents enter the product life cycle too late to influence their development but could create incentives by considering pricing over a longer period, with new funding mechanisms. This could guide manufacturers and create greater cohesiveness in the LLIN product sector.

Emphasizing net durability could, however, have negative consequences. New standards may add costs to product development; increasing the strength and durability of nets could add to production time and negatively impact net acceptability and use by individuals. As recent studies show that human behaviour substantially affects the field life of LLINs, the limited resources might be better spent in encouraging compliance with the current minimum quality standards set during product development and on education and behavioural modification programmes to extend net life in the field. In addition, innovation in current techniques (e.g. modifying textile knitting) could strengthen LLINs, and better monitoring of net distribution programmes could generate data for validating new tests and evaluating the field durability and operational acceptability of new products. Strengthening WHOPES and extending other WHO mechanisms to issue stronger comparative recommendations were also discussed.

3. STUDY OF DURABILITY: RESISTANCE OF NETS TO DAMAGE[1]

Ms Kanika Bahl (R4D, USA) introduced a presentation by Dr Steve Russell on the results of tests by the Nonwovens Innovation and Research Institute on the fabric strength of LLINs. The aim of the project was to determine the fundamental mechanisms of net damage in the field, to design laboratory tests to mimic this damage and to use the tests to develop a composite measure of the resistance of LLINs to damage.

The group determined that 47% of holes in nets may be due to factors other than normal wear and tear (e.g. flames, rodents, cutting). To mimic normal wear and tear, the group identified four parameters related to the causes of holes in used LLINs retrieved from the field: tear resistance, snag strength, abrasion resistance and hole propagation.

The group designed several tests for quantifying these parameters, and used the results to calculate a composite performance value of resistance to damage. The outcomes of the project are summarized below.

STUDY OVERVIEW

A two-phase study was undertaken by collaborators from the Nonwovens Innovation and Research Institute, Tropical Health Limited Liability Partnership (led by Dr Albert Kilian) and R4D to provide a credible technical analysis of the durability of LLINs in a predictive approach, in which the results of textile tests would be correlated with parameters of durability observed in the field. The goal of the study was to facilitate adoption of forward-looking criteria for LLIN durability and innovation by manufacturers.

This summary covers the methods developed and the results obtained in tests of factors that affect the durability of bed nets. Use of different methods might yield different results. Furthermore, the requirements of countries vary; bed nets should be selected for the context and conditions in each country or geographical region. The focus of the study was exclusively the resistance of textiles to damage; issues relating to insecticides were not addressed.

In phase 1, 526 LLINs of six different brands were retrieved in the field in five countries (India, Kenya, Mozambique, Nigeria and Uganda) and analysed to determine the mechanisms that led to net damage and formation of holes. The consortium identified the mechanisms and their relative contributions in different environments by rigorous examination of over 40 000 damage sites by visual inspection, optical microscopy and scanning electron microscopy in the textile laboratory of the Nonwovens Innovation and Research Institute. In phase 2, LLIN textile tests were developed to reflect the actual modes of failure identified and an algorithm to characterize nets in terms of resistance to damage.

[1] Disclaimer: The study by the Nonwovens Innovation and Research Institute and R4D was not undertaken or supervised by WHO. The summary of results presented above is for information for the scientific community and other stakeholders.

STUDY APPROACH

In phase 1, the consortium identified the modes of structural damage to LLINs in different geographical regions, net use patterns and LLIN brands. They found that holes are not formed by a single mechanism but by four broad categories: mechanical, thermal, animal damage and seam failure. Mechanical damage was further categorized into fracture mechanisms: snags, tears, cuts and abrasion. Additionally, after yarn breakage, holes can be enlarged (propagated) by three mechanisms: laddering, unravelling and tearing.

Holes created in nets in the field may be due to normal wear and tear over time or to "severe use". Normal wear and tear is due to forces or damage that would reasonably be expected with appropriate use, while unreasonable use consists of all other forces or damage. For example snagging, tearing, abrasion and hole propagation are difficult to avoid, even if a LLIN is used diligently and with care, and are considered to be normal wear and tear. Thermal damage resulting from exposure to high temperature (e.g. candles, cigarettes or embers from a fire), cutting damage (use of a knife or sharp object to cut the net) or rodent damage (because of food contamination of nets or food stored behind a net) may be considered as due to severe use.

When holes were analysed by area, mechanical damage was the main cause, accounting for 49.6–87.2% of holes, rodent damage accounted for 0–31.1%, thermal damage for 0.9–17.4% and seam failure for 0–39.4%. Although some modes of damage cannot reasonably be expected to occur, the consortium selected test methods to replicate the damage that results from normal wear and tear, by snagging, tearing, abrasion and hole propagation. Tests for characterizing the durability of LLINs were selected on the basis of:

- evidence of damage in the field,
- the degree to which the test replicated damage observed in the field,
- the standard tests currently available and
- the reproducibility of the results obtained with the tests.

On the basis of these criteria, four tests were developed in phase 2: bursting strength (which reflects tearing resistance), snag strength, abrasion resistance and hole propagation or enlargement. Two further tests, of seam strength and thermal stability, were included as parameters of "pass" or "fail". The proposed methods are either standards used in other industries or hybrid standard methods adapted to evaluate the resistance of LLINs to damage. The results of each test correlated well with field data; i.e. snag strength was strongly correlated with the number of snags observed in nets from the field.

Subsequently, two systematic approaches were developed for evaluating the resistance of nets on the basis of the results of the tests, in a two-step process. First, minimum threshold values were set on the basis of safety and stability (thermal stability and seam strength); then, an algorithm was applied to generate a single value for resistance to damage (RD value). The target value was based on consideration of the actual forces likely to be encountered in the field in normal wear and tear.

RECOMMENDATIONS

The tools developed in this study could be used to assess and compare the resistance of LLINs to common damage mechanisms in the field; however, several elements are critical for the credibility and validity of the results. The batches of nets submitted for durability testing in the laboratory and those sent to the field must comply with WHO (or, if not available, the manufacturer's) specifications and hence be likely to perform similarly. Currently, specifications prepared by manufacturers according to WHOPES guidelines are reviewed by the WHO/FAO Joint Meeting on Pesticide Specifications.[1] Those for LLINs include a detailed description of the net (polymer type, denier, chemical content), the

[1] Manual on development and use of FAO and WHO specifications for pesticides. 2nd edition. Geneva/Rome: World Health Organization/Food and Agricultural Organization of the United Nations; 2010 (http://whqlibdoc.who.int/publications/2006/9251048576_eng_update3.pdf).

active ingredient(s) and relevant impurities, the physical properties of the net (e.g. mesh size, bursting strength) and its stability in storage. The specifications could be extended to include the additional durability parameters suggested in this study. Purchasers should test the quality of nets to confirm that they match their specifications. As for all specifications, if durability is to be included in WHO specifications, manufacturers will submit to WHO their own data, generated according to guidelines. Once the new methods have been validated, technical data on durability could be reviewed and validated by the WHO/FAO Joint Meeting on Pesticide Specifications. Annex 4 introduces values for resistance to damage.

DISCUSSION

Tier classification system and use of the resistance to damage value. The pros and cons of a tier classification system were discussed at length. While such a system might provide an incentive to improve a net that performs poorly, questions were raised about who would do the classification and review scores for resistance to damage and how the system would affect net distribution. The tier system might generate confusion about the functionality of nets within tiers and would raise the problem of deciding who would receive nets in a higher tier. The tier system cannot be used as a negotiating point for LLINs that are replaced every 3 years.

Exploring value for pricing structure for LLINs. The meeting agreed that high-level talks should be held between the Vector Control Technical Expert Group of the Global Malaria Programme and procurement agencies to discuss the provision of funding for field studies on the durability of different brands of LLIN. Such studies are needed to inform LLIN replacement policies. LLINs with longer life cycles may need to be replaced less frequently, thus reducing the costs of LLIN distribution.

Method adoption, validation and integration into current LLIN evaluation mechanisms. Manufacturers and experts agreed that all tests to be included in net specifications should be validated to ensure inter-laboratory accuracy and comparability before they are accepted.

Effect of behaviour on LLIN performance in the field. The field performance of LLINs depends on the behaviour and culture of users. Behaviour can be changed by communication programmes designed to lengthen the life span of nets. Inherent differences in field durability between LLINs may be more apparent if severe net use and any associated damage were be decreased. Although common mechanisms of damage were observed in the field, more work is needed to understand the amount of damage sustained in different locations.

WHO made procedural clarifications during the discussion. The mechanism for changing the current 3-year replacement policy for LLINs would be through the Vector Control Technical Expert Group, which would evaluate the evidence and issue a position statement for consideration by the Malaria Policy Advisory Committee. Product specifications can be revised at any time but must be based on accepted, standardized test methods. WHO specifications can be changed through the WHO/FAO Joint Meeting on Pesticide Specifications. As new methods become available, they can be included in the FAO/WHO manual on pesticide specifications, which is supplemented annually. Once the specifications have been formalized, all nets will have to comply with them.

Manufacturers were generally supportive of efforts to improve inherent fabric strength and durability but voiced concern about the value of improving net durability, given the current 3-year net replacement policy, the effect of severe use on net life in the field and the trade-offs that may accompany improvements in fabric strength including cost of production and the bioavailability of insecticides. The group said that minimum quality criteria should be set in order to integrate WHO specifications and discussed how nets already on the market would be compared with the new criteria. A concern of this interest group was whether net performance will mean different pricing structures for LLINs and whether incentives will produce incremental or sudden improvement. Manufacturers called for procurers to consider the market space for improved products, which are likely to be 10–15% more expensive than standard nets.

Comments were made on current procurement structures and the need for evidence on value-for-money pricing of LLINs, a shift that might, as seen for rapid diagnostic tests, improve the baseline quality of nets on the market and create incentives for innovation.

The current LLIN replacement policy discourages spending on improving nets; innovations in net durability should lead to a change in WHO policy. The basic quality of nets should be improved, and they should comply with specifications.

4. DISCUSSION AND CONCLUSIONS

How likely an LLIN is to develop holes during everyday use and, should holes develop, how likely it is that they will enlarge, compromising the barrier function of the net, have important implications for net durability in the field and for making procurement decisions on LLINs. Between March 2013 and July 2014, WHO undertook a study to determine the physical strength of the netting materials of WHO-recommended LLINs with standard fabric criteria and tests. A study was undertaken concurrently by the Nonwovens Innovation and Research Institute and R4D to develop predictive measures of LLIN durability by correlating textile test data with LLIN durability in the field. The WHO consultation held on 20–22 August 2014 reviewed the data from two phases of the WHO study and discussed the results of the Nonwovens Innovation and Research Institute–R4D study. The results of the two studies indicated that WHOPES-recommended LLINs vary in fabric strength and indicated that additional parameters should be added to LLIN specifications, such as fabric weight and flammability. All the methods should be validated in inter-laboratory studies before they are included in WHO specifications. Furthermore, multi-centre studies should be undertaken on the durability of LLINs under operational conditions. These data could be used to improve the minimum specifications for quality control, stimulate improvements in quality and innovation of LLINs and inform policy recommendations.

While the WHO study reviewed at the consultation addressed the inherent fabric strength of LLINs, the usefulness of the tests for predicting their durability in the field has yet to be determined. The necessary field data could be collected in comparative prospective studies with various brands of LLINs used in a single study environment. The WHO study was limited by a potential bias in the results for LLIN performance because the nets were submitted by manufacturers; follow-up studies will be conducted with nets collected randomly in the field.

Targeting the distribution of nets on the basis of intrinsic fabric strength and an assessment of the risk in the target area will require additional information. A substantial amount of evidence, and both time and resources, will be required to collect and review field data on net durability and to link them with fabric strength, the use environment and net culture. Funding mechanisms should be put in place to collect such data by well-supported, practical criteria. Additionally, quality control of LLINs should be improved, with respect to compliance by manufacturers with both the specifications and WHO-recommended practice for quality control during procurement. Educational programmes to promote correct use and maintenance of nets may be indicated to prolong their life. Net durability and performance criteria will be useful for informing procurement practice and for encouraging innovation in designing longer-lasting nets.

FABRIC STRENGTH TEST METHODS: SUMMARY OF DISCUSSION

Each method was discussed in detail to determine what further data were required to refine them. The experts considered how relevant the laboratory tests were to net durability and performance in the field and discussed aspects of the methods such as validation of ISO methods, thresholds and sample sizes. The discussions and recommendations for the methods are summarized in Table 1.

Table 1. Summary of discussion on methods for testing fabric strength

Test method	Discussion points and recommendations
Bursting strength (method EN ISO 13938-2)	The method should be restricted to the pneumatic method.
Flammability (method 16 CFR Part 1610 and EN 1102)	These consist of a 45° angle test and a vertical test. The vertical flammability test (EN 1102) should not only be incorporated into WHO specifications but be a requirement for all nets entering the WHOPES programme. Detailed, standardized procedures should be specified for methods and for calculating sample size.
*Hook tensile strength (method ISO 13934-2)	The test measures the tendency of materials to rapture and snag. While similar to the snag test (below), it is also a measure of how holes propagate after an initial snag. As for other tests, the results must be correlated with performance in the field and all the protocols standardized.
*Snag test (adapted from EN 15598)	The test measures the force required to break the yarn in a fabric, creating a hole. It is designed to estimate the basic resistance of a fabric to initial filament breakage. The results of this slightly modified ISO method correlate well with field data.
*Wounded bursting strength (EN ISO 13938-2)	While the results of this test have not been correlated with field data, it is useful, as no other test is available to evaluate tearing of netting material after wounding.
*Hole propagation (adapted from the wounded burst test)	This test evaluates how holes in nets enlarge by secondary mechanisms such as laddering, unravelling and tearing. The results add to those of the wounded bursting strength test in understanding the propagation of holes.
*Wounded bursting strength (EN ISO 13938-2)	While the results of this test have not been correlated with field data, it is useful, as no other test is available to evaluate tearing of netting material after wounding.
*Abrasion resistance (adapted from ISO 12947:1998)	This test measures the susceptibility of a sample to abrasion, which is an important cause of damage in the field. The reproducibility of the results obtained with this test was questioned. It must be standardized and validated before widespread use.
Seam stability (adapted from the bursting strength test)	Current WHO methods for testing bursting strength could be adapted to test seam stability. This would require setting new thresholds for the test, defining where on the netting (e.g. seams) the test should be performed and minor modifications to equipment.
Fabric weight (EN 12127)	CFabric weight should be included in WHO specifications. As it is an indirect measure of denier, it can be used to cross-check denier specifications. The test is also relevant for expressing the insecticide content in an LLIN product as mg/m² from the content measured as g/kg.

Note: Test methods marked with a (*) will require inter-laboratory validation.

The meeting also discussed whether information about the tests should be made publically available. The idea of a "resistance-to-damage" score was broadly supported and accelerating the collection of field data to stimulate innovation and the development and deployment of new products to the field. Ways must be found to generate the evidence necessary to improve resistance-to-damage scores regularly. The scores are currently estimated by equal weighting of four parameters. More work is required to validate use of the score and to determine whether the parameters should contribute differentially. Members of the expert panel also called for field studies of different brands of nets in the field in different countries and use situations, with clear protocols, to provide evidence for procurement decisions.

5. RECOMMENDATIONS

The meeting made the following recommendations.

- WHOPES should coordinate inter-laboratory validation of test methods (*Table 1*), subject to the availability of funding. WHOPES will coordinate the drafting of guidelines for testing the physical strength of LLINs.
- WHO should revise the LLIN specification guidelines to include fabric weight, flammability and other fabric characteristics, after validation of the tests.
- WHO should recognize the value of resistance-to-damage scores based on the proposed combination of tests and make the score for each brand of LLIN available on a limited basis.
- The resistance to damage approach and method should be updated regularly, as new evidence becomes available, and clear mechanisms should be in place to ensure updating.
- Resistance-to-damage scores should be updated regularly to promote manufacturer innovation, with support from major financers, WHO and manufacturers.
- WHO should coordinate multi-centre comparative studies of the durability of LLINs under field conditions by established methods. International donor agencies, including the Global Fund and the President's Malaria Initiative, should fund the collection and sharing of comparable, standardized field data on LLIN performance, including accelerated evaluation of durability, to better evaluate improved performance.
- The feasibility and value of a tier system should be revisited once inter-lab validation has been completed and the range of available LLINs has been tested with the agreed set of tests.
- The global community should invest in evidence-based approaches to change social behaviour to promote adequate care and maintenance of LLINs and minimize sources of potential damage such as cutting nets, exposing them to flames and accumulating food residues on or near nets.
- The capacity of WHO to address these recommendations should be enhanced by additional staff and funding dedicated to monitoring the durability of LLINs.

ANNEXES

ANNEX 1. AGENDA

WHO consultation to determine and compare the fabric strength of WHOPES-recommended long-lasting insecticidal nets (round 2)

WHO, Geneva, Switzerland, 20–22 August 2014

Wednesday 20 August

Closed session (limited to temporary advisers and WHO Secretariat)

- Declarations of interest
- Working procedure
- Other matters

Open session (all participants)

1. Opening of the meeting and welcome address
    - Welcoming address and introductory remarks – *Dr John Reeder*
    - Administrative arrangements and introduction of participants – *Dr Raman Velayudhan*
    - Objectives of the meeting – *Dr Abraham Mnzava*
    - Quality control parameters in current WHO specifications of LLINs – *Dr Rajpal Yadav*
2. Appointment of Chairperson and rapporteurs
3. Presentation of the report of the WHO study – *Dr Stephen Smith*
4. Presentation of the report of the R4D study on net durability – R4D Institute
5. Discussion and brain-storming
    - What have we learnt from the studies?
    - What additional parameters would be useful to include in LLIN specifications as part of quality control?
    - How can the study outcomes inform the determination of net durability?
    - How can the study outcomes inform procurement decisions?
    - Next steps

Thursday 21 August
Open session

Friday 22 August

Closed session (limited to temporary advisers and WHO Secretariat)

6. Review and finalization of report
7. Conclusions and recommendations
8. Closure

ANNEX 2. LIST OF PARTICIPANTS

WHO temporary advisers

Ms Ana Fonte, Centro Tecnológico das Indústrias Têxtil e do Vestuário, Vila Nova de Famalicao, Portugal
Dr John Gimnig, Centers for Disease Control and Prevention, Atlanta, Georgia, USA
Dr Margaret Gyapong, Ghana Health Service, Accra, Ghana
Dr Hmooda Kafy, Federal Ministry of Health, Khartoum, Sudan
Dr Albert Kilian, Tropical Health LLP, Montagut, Spain
Dr Jo Lines, London School of Hygiene and Tropical Medicine, London, United Kingdom
Dr Shishir Kumar Pant, Vector Borne Disease Research, Makwanpur, Nepal
Dr Olivier Pigeon, Walloon Agricultural Research Centre, Gembloux, Belgium
Dr Melanie Renshaw, African Leaders Malaria Alliance, Cornwall, UK
Dr Stephen Russell, Nonwovens Innovation & Research Institute Ltd, Leeds, UK
Dr Stephen Smith, Centers for Disease Control and Prevention, Atlanta, USA
Dr Suman Lata Wattal, National Vector-Borne Disease Control Programme, Delhi, India

LLIN manufacturers

Mr Rune Bosselmann, Tana Netting, Dubai, United Arab Emirates
Mr Nick Brown, A to Z Textile Mills Ltd, Arusha, United Republic of Tanzania
Mr Andy Butenhoff, Disease Control Technologies LLC, Greer, South Carolina, USA
Mr Li Chenbiao, Tianjin Yorkool International Trading Co Ltd, Tianjin, China
Mr Rod Flinn, Disease Control Technologies LLC, Greer, South Carolina, USA
Dr Gerhard Hesse, Bayer SAS, Lyon, France
Mr John Invest, Sumitomo Chemical, Plymouth, Cornwall, UK
Dr Ramanathan Natarajan, V.K.A. Polymers Pvt Ltd, Karur, Tamil Nadu, India
Dr Helen Pates-Jamet, Vestergaard-Frandsen, Washington DC, USA
Mr William Paton, Life Ideas Textiles Co Ltd, Beijing City, China
Mr Anand Samiappan, V.K.A. Polymers Pvt Ltd, Karur, Tamil Nadu, India
Dr Frederic Schmitt, Bayer SAS, Lyon, France
Mr Marappan D. Sivasamy, Shobikaa Impex Pvt Ltd, Karur, Tamil Nadu, India
Dr Ole Skovmand, Intelligent Insect Control, Castelnau le Lez, France
Mr Thomas Soerensen, Vestergaard Frandsen Group SA, Lausanne, Switzerland
Mr Yoshihiro Takebayashi, Sumitomo Chemical, Tokyo, Japan
Dr Egon Weinmüller, BASF SE, Limburgerhof, Germany
Dr Zhao Zhou, Tianjin Yorkool International Trading Co. Ltd, Tianjin, China

Observers

Dr Kanika Bahl, Results for Development Institute, Washington DC, USA

Dr Joelle Daviaud, Global Fund to Fight AIDS, Tuberculosis and Malaria, Geneva, Switzerland

Dr Christen M. Fornadel, United States Agency for International Development, Washington DC, USA

Mr Christopher Game, Global Fund to Fight AIDS, Tuberculosis and Malaria, Geneva, Switzerland

Dr Mariatou Tala Jallow, Global Fund to Fight AIDS, Tuberculosis and Malaria, Geneva, Switzerland

Dr Jan Kolaczinski, Global Fund to Fight AIDS, Tuberculosis and Malaria, Geneva, Switzerland

Mr Bruno Moonen, Bill & Melinda Gates Foundation, Seattle, Washington, USA

Dr Jacob Williams, RTI International, Washington DC, USA

WHO regional offices

Dr Rabindra Abeyasinge, WHO Regional Office for the Western Pacific, Manila, Philippines

Dr Ritha Njau, WHO Regional Office for Africa, Dar-es-Salaam, United Republic of Tanzania

WHO Secretariat

Dr Magali Sophie Babaley, Roll Back Malaria Partnership

Dr Anna Drexler, Vector Ecology and Management, Department of Control of Neglected Tropical Diseases

Dr Dirk Engels, Department of Control of Neglected Tropical Diseases

Dr Stefan Hoyer, Vector Control Unit, Global Malaria Programme

Dr Tessa Knox, Global Malaria Programme

Dr Abraham Mnzava, Vector Control Unit, Global Malaria Programme

Dr Bernadette Ramirez, Special Programme for Research and Training in Tropical Diseases

Dr John Reeder, Global Malaria Programme

Dr Emmanuel Temu, Vector Control Unit, Global Malaria Programme

Dr Raman Velayudhan, Vector Ecology and Management, Department of Control of Neglected Tropical Diseases

Dr Rajpal Yadav, Vector Ecology and Management, Department of Control of Neglected Tropical Diseases

ANNEX 3. REPORT OF THE WHO STUDY ON DETERMINATION OF THE FABRIC STRENGTH OF WHOPES-RECOMMENDED LONG-LASTING INSECTICIDAL NETS

ACKNOWLEDGEMENTS

The WHO Global Malaria Programme and the Department of Control of Neglected Tropical Diseases gratefully acknowledge the financial support of the Global Funds to Fight Aids, Tuberculosis and Malaria. WHO also acknowledges the manufacturers of LLINs for providing their nets free of charge for the study.

All the tests were conducted at the laboratories of the Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal in Vila Nova de Famalicão, Portugal. WHO expresses its sincere thanks and appreciation to Ms Ana Fonte of the institute.

Dr Steve Smith, US Centers for Disease Control and Prevention, analysed the data from the study and drafted the report.

INTRODUCTION

Currently, 11 long-lasting insecticidal nets (LLINs) are recommended by WHOPES for malaria prevention and control.[1] Assessment of several of these LLINs in different settings has shown that the strength of the netting fabric and the durability of these products vary. The WHO guidelines for monitoring the durability of LLINs under operational conditions[2] and for procuring public health pesticides[3] promote the concept of value-for-money and improving the quality of LLINs; however, insufficient comparative data are available on the durability of LLINs in different countries to discriminate among the WHOPES-recommended LLINs for making procurement decisions. Price and lead time are the two criteria widely used in procuring LLINs, while no distinction is made with regard to quality or inherent fabric strength. Ideally, cost per year of net life under local conditions of use should guide the selection and procurement of LLINs. Therefore, for national procurement decisions, data are needed on LLIN durability at country level.

Field data on the durability of LLINs should be linked to the specifications of the netting material; however, the only two fabric strength parameters included in WHO specifications for LLINs[4] are bursting strength and denier. The specifications for fabric strength should therefore be improved, as bursting strength and denier are insufficient to properly reflect the strength of netting material or stitched nets. LLINs are subject to a wide variety of physical stresses during use that are unlikely to be captured by these two measures alone. Additional measures of strength would also result in better quality control of LLINs. To improve the quality of fabric strength, it would be useful to compare WHOPES-recommended LLINs, develop a composite weighted scale of fabric strength, study common causes of wear and tear in operational use, set criteria and design laboratory studies to simulate field use. Countries, especially those where LLINs are most widely used, should be supported in collecting data on the durability of different LLINs in a range of operational conditions.

The WHO Global Malaria Programme and WHOPES conducted a laboratory study during 2013–2014 to determine the fabric strength of LLINs and thus improve the WHO specifications. The report of the study is presented below.

OBJECTIVE AND SCOPE

The main objective of the study was to determine and specify the physical strength of the netting materials used in WHO-recommended LLINs on the basis of standard criteria and test methods. WHO specifications for the fabric strength of LLINs and netting material are required for interpreting data on the durability of LLINs in the field and for making procurement decisions. The goal of the study was to promote the development of good-quality LLINs and the concept of value-for-money in the procurement of these essential public health products. The outcomes of the study should be useful for both procurement agencies and for product development by industry.

[1] WHO recommended long-lasting insecticidal nets. Updated 06 February 2014. Geneva: World Health Organization; 2014 (http://www.who.int/whopes/Long_lasting_insecticidal_nets_06_Feb_2014.pdf).

[2] Guidelines for monitoring the durability of long-lasting insecticidal mosquito nets under operational conditions. Geneva: World Health Organization; 2012 (WHO/HTM/NTD/WHOPES/2012.4) (http://whqlibdoc.who.int/publications/2011/9789241501705_eng.pdf).

[3] Guidelines for procuring public health pesticides. Geneva: World Health Organization; 2012 (WHO/HTM/NTD/WHOPES/2012.4).

[4] Manual on development and use of FAO and WHO specifications for pesticides. Geneva: World Health Organization; 2010 (http://who.int/whopes/quality/en/).

TEST MATERIALS

The LLINs tested are listed in Table A3.1 . Nets were supplied by their manufacturers with a product identification form giving the details listed in the table. The nets tested included 11 WHOPES-recommended LLINs (including Olyset Net V.2, which has a different knitting pattern from that of Olyset Net) and three LLIN brands that were in phase-II trials at the time of the study (Miranet, Panda Net 2.0 and Yahe). The WHO interim recommendation for use of Netprotect was withdrawn by WHOPES in October 2013,[1] but the fabric strength parameters of this net are listed in the report and table to demonstrate the fabric strength of a 110-denier polyethylene monofilament net. Photomicrographs of representative samples of each net are shown in *Figure A3.1*.

Table A3.1. Characteristics of nets used in the study

LLIN	Manufacturer	Batch No.	Polymer	Colour	Denier[5]	Filaments per yarn	Mesh (holes/cm^2)
DawaPlus 2.0 LN[1]	Tana Netting, United Arab Emirates	No information No information	PET	White	75 100	36 36	≥ 24 ≥ 24
Duranet LN	Shobikaa Impex Pvt Ltd, India	397856GR03133 237856GR03133 567856GR03133	PE	Green	150	1	≥ 20
Interceptor LN	BASF, Germany	4905735152; November 2012 4559810350; October 2011 4559308892 September 2011 4561030749; May 2009 No information; October 2009 4560947703; April 2010	PET	White	75	≥ 32	≥ 24
LifeNet LN	Bayer, Germany	AR12019-AR12022 AR12020-AR12023 AR12027-AR12027	PP	White	118	24	21–29
MagNet LN	VKA Polymers Pvt Ltd, India	MN-0-165 MN-0-166 MN-0-168	PE	White	150	1	≥ 20
Miranet LN[2]	A to Z Textile Mills Ltd, United Republic of Tanzania	0801 09 AGS 0801 12 AGS 0801 14 AGS	PE	Blue	130	1	≥ 20
NetProtect LN[3]	Bestnet A/S, Denmark	5 111908 004, March 2012 5 132502 033, April 2013 5 121406 010, July 2012	PE	White Green Red/blue	118 118 118	1 1 1	≥ 20 ≥ 20 ≥ 20
Olyset Net LN	Sumitomo Chemical, Japan	OL30521-1, 21 May 2013 OL30521-2, 21 May 2013 OL30521-3, 21 May 2013	PE	White	≥ 150	1	≥ 8
Olyset Net LN (v.2)[4]	Sumitomo Chemical, Japan	OL30527-1, 27 May 2013 OL30527-2, 27 May 2013 OL30527-3, 27 May 2013	PE	White	≥ 150	1	≥ 8

[1] For details, see Report of the 16th WHOPES working group meeting—review of pirimiphos-methyl 300 CS, chlorfenapyr 240 SC, deltamethrin 62.5 SC-PE, Duranet LN, Netprotect LN, Yahe LN, Spinosad 83.3 Monolayer DT, Spinosad 25 extended release GR. Geneva: World Health Organization (WHO/HTM/NTD/WHOPES/2013.6) (http://www.who.int/whopes/recommendations/wgm/en/).

Table A3.1. (Contd)

LLIN	Manufacturer	Batch No.	Polymer	Colour	Denier[5]	Filaments per yarn	Mesh (holes/cm²)
Olyset Plus LN	Sumitomo Chemical, Japan	OP21206-1, 6 December 2012 OP21206-2, 6 December 2012 OP20126-3, 6 December 2012	PE	Blue	150	1	≥ 12
Panda Net 2.0 LN[2]	LifeIdeas Textiles Co. Ltd, China	LNN31116A-HDPE LNN31115A-HDPE LNN31116B-HDPE	PE	Blue	120	1	≥ 20
PermaNet 2.0 LN	Vestergaard Frandsen, Switzerland	101313 101413 110513 120713 128713 128813	PET	White	75 100	≥ 32 ≥ 32	≥ 24 ≥ 24
PermaNet 2.0 LN	Vestergaard Frandsen, Switzerland	114913 123613 119213 117313 117413 117713	PET sides PE roof	White Blue White Blue White Blue White Blue White Blue White Blue	75 100 75 100 75 100 100 100 100 100 100 100	32 1 32 1 32 1 32 1 32 1 32 1	≥ 24 ≥ 21 ≥ 24 ≥ 21 ≥ 24 ≥ 21 ≥ 24 ≥ 21 ≥ 24 ≥ 21 ≥ 24 ≥ 21
Royal Sentry LN	Disease Control Technologies, USA	092T21BL06122 831290GR03123 372298WT12101	PE	Blue Green White	150 150 150	1 1 1	≥ 20 ≥ 20 ≥ 20
Yahe LN[2]	Fujian Yamei Industry & Trade Co. Ltd, China	YMIOTH1205/22/23 YMLN1303/12/19 YMLN1304/16/20	PET	White	75	36	≥ 24
Yorkool LN	Tianjin Yorkool International Trading Co. Ltd, China	D1206GH, June 2012 1208UG, August 2012 D1105LA, May 2011 1207ML, July 2012 1211TJ, November 2012 1105BN, May 2011	PET	Blue White Green White White Blue	75 75 75 100 100 100	36 36 36 48 48 48	≥ 24 ≥ 24 ≥ 24 ≥ 24 ≥ 24 ≥ 24

PE = polyethylene; PET = polyester; PP = polypropylene

[1] Only Tana Netting, United Arab Emirates, provided more than one sample of netting.

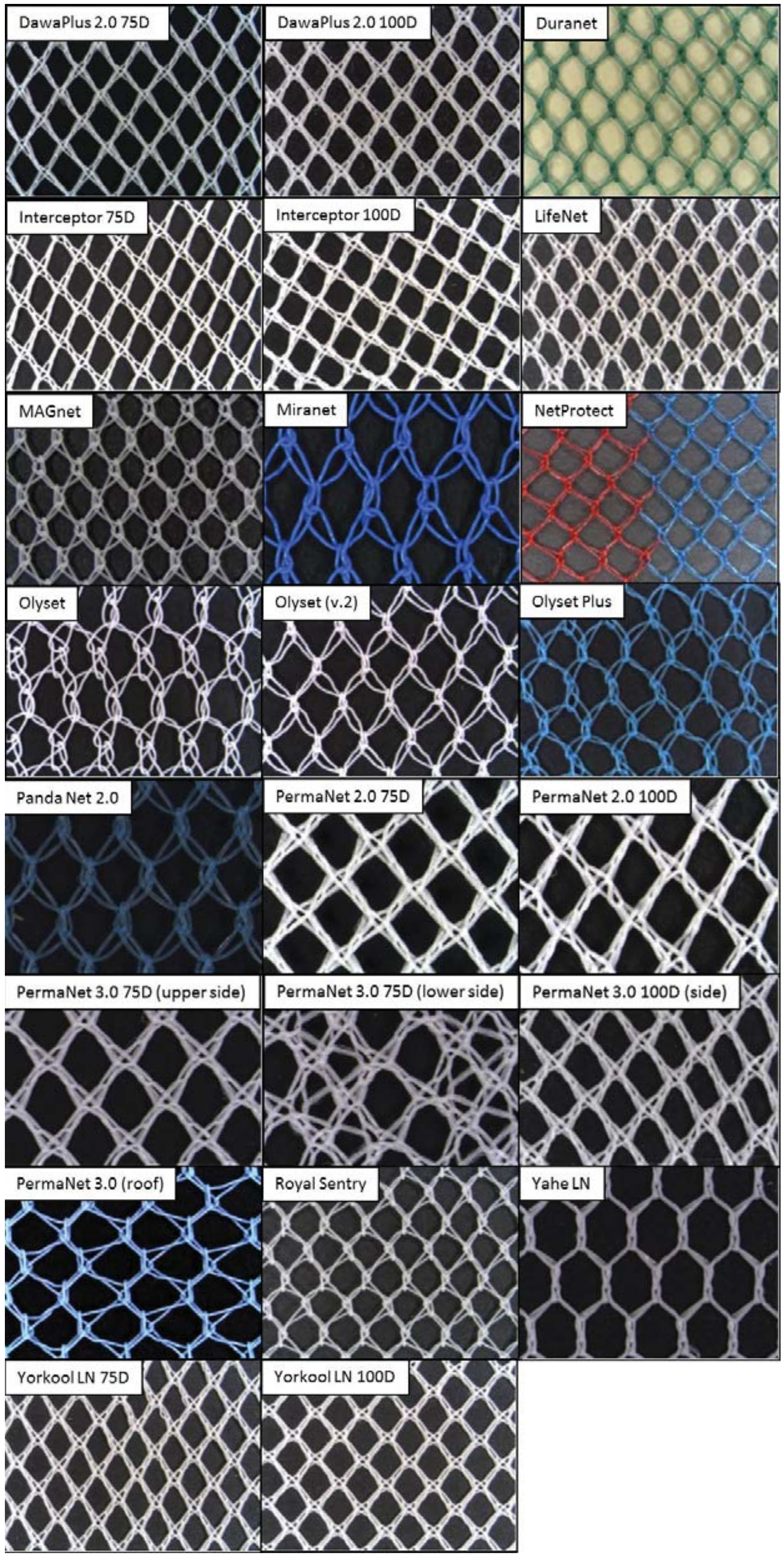
[2] As of December 2014, these nets are still undergoing WHOPES phase-II evaluation and therefore not recommended for use in malaria control.

[3] As of October 2013, WHOPES interim recommendation on use of this LN was withdrawn by WHO.

[4] Olyset Net LN (v.2) is just Olyset Net LN with a different knitting pattern.

[5] Denier values were provided by the manufacturers as they cannot be measured in the laboratory.

FIGURE A3.1. Representative photomicrographs of the nets tested, showing details of the knit structures



PermaNet 3.0 LLINs consist of a combination of polyethylene (for the roof) and polyester (for the side panels) fabrics. The two types of fabric were tested separately. Three of the PermaNet 3.0 nets supplied had a 100-denier polyethylene roof and 100-denier polyester side panels; the other three nets had a 100-denier polyethylene roof and 75-denier polyester side panels. The upper portion weighed 32 g/m^2 and the lower strengthened border portion weighed 44 g/m^2, because the two regions had different knitting patterns, resulting in different fabric weights.

METHODS

GENERAL CONSIDERATIONS

All tests were conducted at the Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal laboratories in Vila Nova de Famalicão, Portugal, which also supplied all the photographs used in this document of the representative net materials supplied by the manufacturers.

All the tests were carried out with published standard methods, with two exceptions—the wounded bursting strength and hook tensile strength tests—which are modifications of standard textile methods. Although standard methods were used, every method may not be suitable for all materials. For example, the results for a material that ruptures inconsistently in a strength test may be poorly reproducible, especially between laboratories. Therefore, before quantitative results can be accepted, each test must be evaluated for suitability.

During the study, flammability testing was added in order to compare LLIN performance under the 16 CFR 10 test specified by WHOPES with the European standard EN 1102 flammability test for curtains.

Many specimens were tested in both “length” and “width” directions, because all LLINs are made by warp knitting. In this process, the yarns are oriented in the direction in which the fabric emerges from the knitting machine (“warp direction”), and the strength of the fabric varies according to the direction of the stress relative to the warp. In oriented materials such as these, fabric strength is usually measured both 0° and 90° relative to the warp direction, which correspond to the “length” and “width”, respectively, as reported by Centro Tecnológico das Indústrias Têxtil e do Vestuário.

Testing was conducted in two rounds. During the first round, the LLINs tested were: DawaPlus 2.0 LN, 75 and 100 denier); Duranet LN; Interceptor LN, 75 and 100 denier; LifeNet LN; MagNet LN; Netprotect LN; Olyset Net LN; Olyset Net LN (version 2); Olyset Plus LN; Royal Sentry LN; and Yorkool LN, 75 and 100 denier. These LLINs were examined in all the tests except for the wounded bursting strength test.

On 21–23 August 2013, a technical consultation was convened by WHO in Geneva to discuss the results of this round of testing. During the meeting, it was decided that, for the sake of completeness, other LLINs, either recommended by WHOPES or in phase-II evaluation, should be tested in the same battery of tests, except for the trouser, wing and tongue tear tests. A second round of testing was therefore carried out on PermaNet 2.0 LN and PermaNet 3.0 LN, 75 and 100 denier; and also on Miranet LN, Panda Net 2.0 LN and Yahe LN, which were still undergoing WHOPES phase-II evaluation at the time and are therefore not recommended for use in malaria control.

It was further decided to conduct a modified bursting strength test (called the “wounded” bursting strength test by the consultation) on all the nets included in both rounds. In this test, samples receive a small cut, and their ability to retain strength after minor damage is tested.

FABRIC WEIGHT (METHOD EN 12127)

As fabric weight influences strength, it was measured for each net. Five specimens were cut from each net with a cutter designed for the purpose, which holds the netting flat against a cutting surface while a set of wheels cuts a 100-cm2 circular specimen (*Figures A3.2* and *A3.3*). As LLIN netting is lightweight, the net must be held firmly against the surface to prevent distortion during cutting, which would result in an uneven cut. Cut specimens were weighed on a balance and the result multiplied by 100 to give results in g/m^2.

FIGURE A3.2. Measuring fabric weight: device for cutting a 100-cm^2 circular specimen

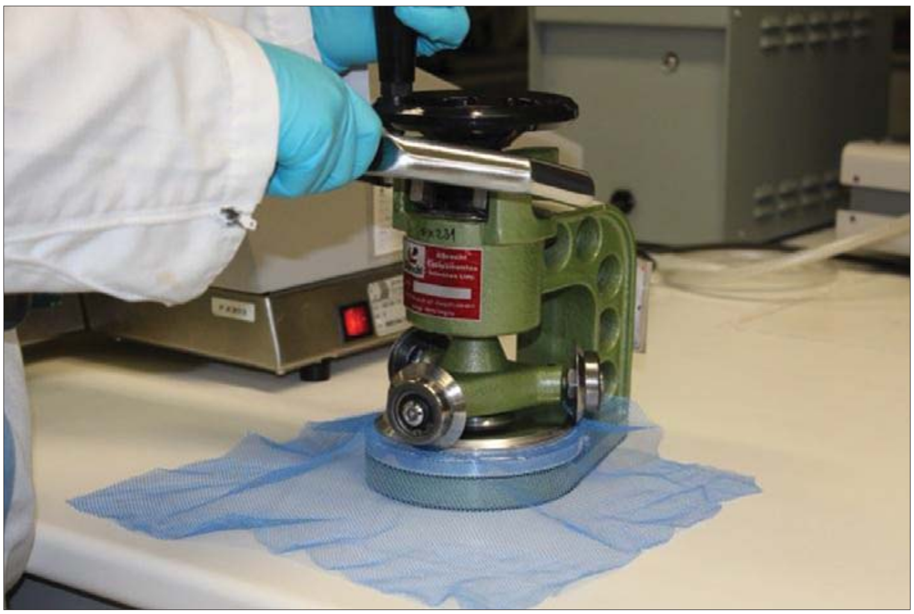
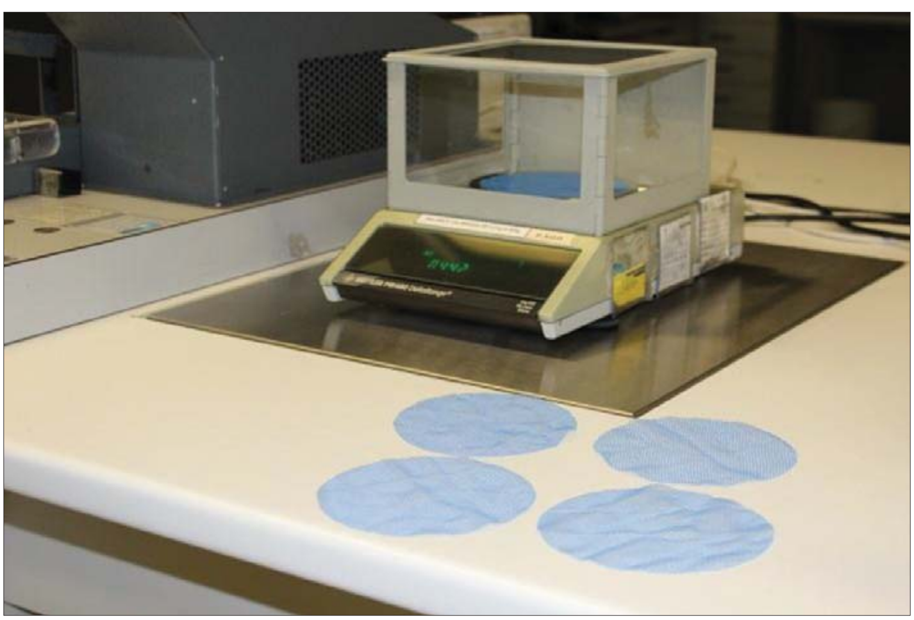


FIGURE A3.3. Measuring fabric weight: weighing 100-cm^2 circular specimens



BURSTING STRENGTH (METHOD EN ISO 13938-2)

The standard pneumatic bursting strength test was used, with a modified test for "wounded" samples. Bursting strength is commonly tested to measure the strength of knitted fabrics.[1] The test apparatus applies stress to the specimen in all lateral directions simultaneously, so multiple tests need not be conducted on samples in various orientations. Uniaxial tensile strength tests often cause excessive necking and roping in knitted fabrics, confounding interpretation of the results. Bursting strength is currently the only WHOPES-specified strength test for LLINs. In order to obtain WHOPES recommendation, LLINs must have a minimum bursting strength of 250 kPa for both the netting and the seams.

A common criticism of this test is that bursting is not a likely mode of failure for LLINs in the field, and the relevance of this method for predicting the durability of LLINs remains unproven.

The method calls for a pneumatic testing apparatus (*Figures A3.4–A3.8*) with a circular clamping device that fixes the specimen against a 1-mm rubber diaphragm. The circular testing area is 7.3 cm^2. Air pressure is applied to the side of the diaphragm opposite the net specimen, and the diaphragm is forced against the specimen. As the pressure is increased, the specimen ultimately bursts; the pressure and diaphragm distension are recorded at the moment of bursting. After subtraction of the pressure required to distend the diaphragm to the same point with no specimen, the net bursting strength of the specimen is obtained (in kPa).

FIGURE A3.4. Apparatus for testing pneumatic bursting strength

[1] Saville BP. Physical testing of textiles. Abington, Cambridgeshire: Woodhead Publishing Ltd; 1999:154.

FIGURE A3.5. Apparatus for testing bursting strength with netting sample clamped in place

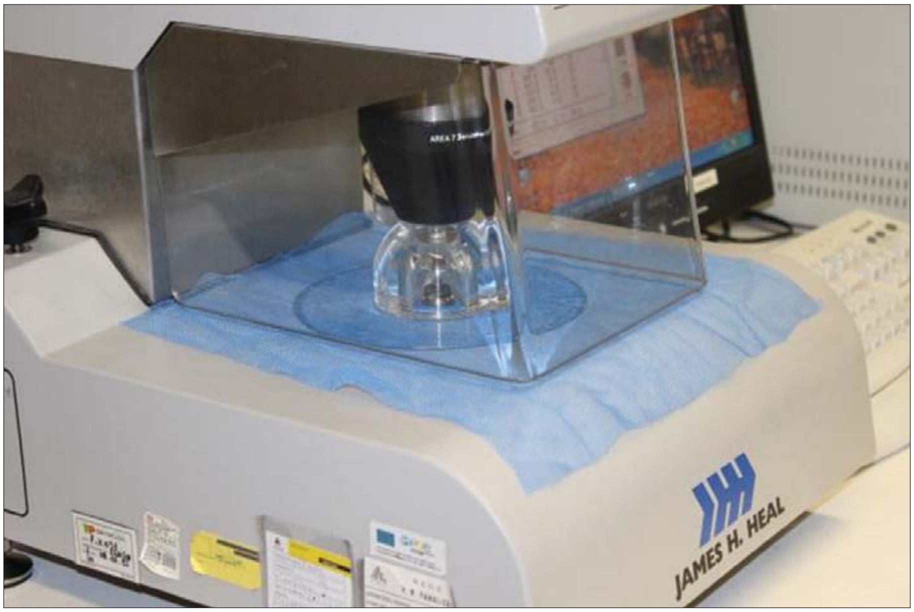


FIGURE A3.6. Bursting strength test: diaphragm inflating behind netting specimen

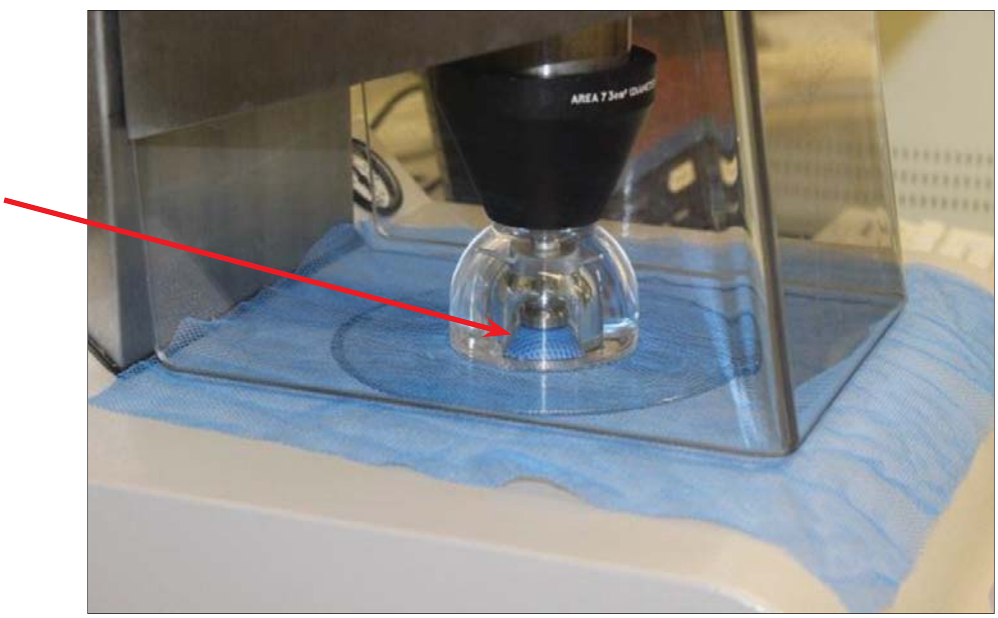


FIGURE A3.7. Bursting strength test: burst netting sample at end of testing (unclamped)

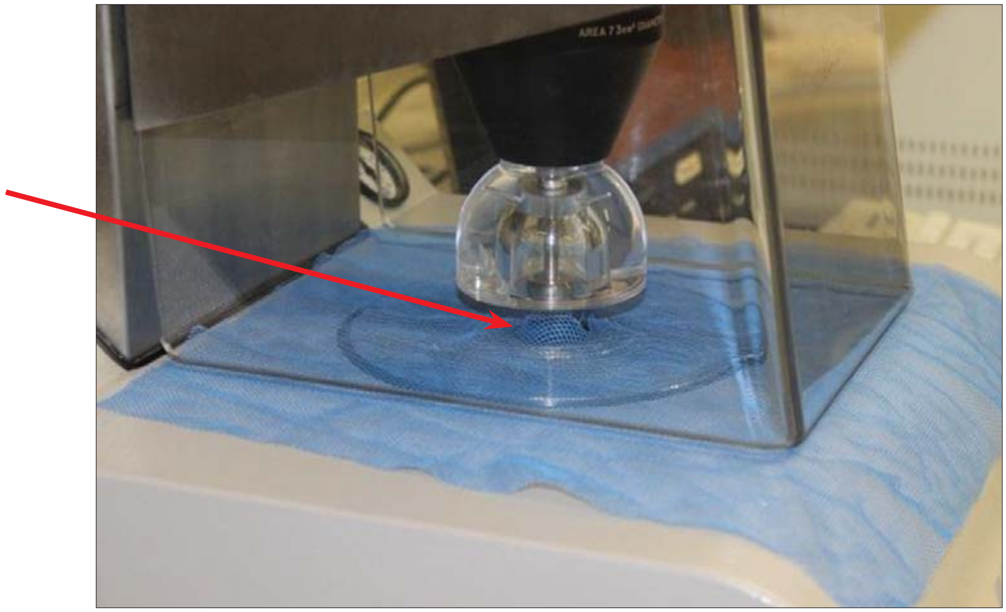
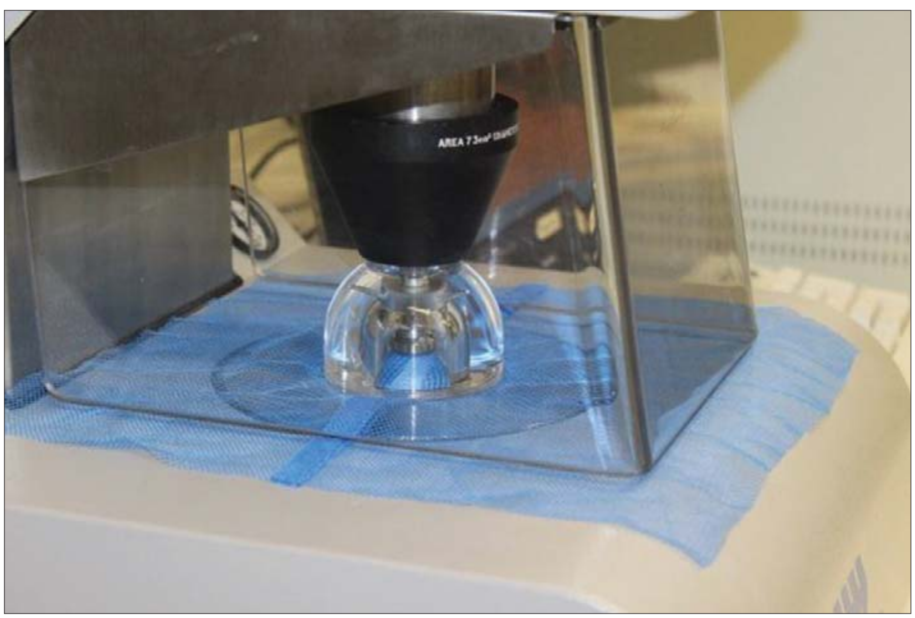


FIGURE A3.8. Testing the bursting strength of a seam

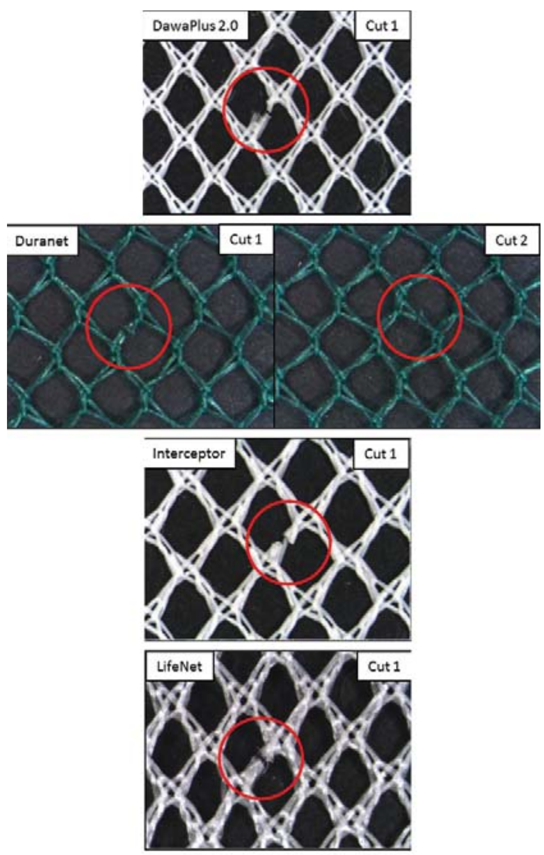


The proper rate of pressurization must be determined before the test is started. The instrument is set so that the sample bursts in 20 ± 5 s. Before testing another LLIN or changing from testing netting to testing seams, the proper pressurization rate must be re-established. Once the rate is established, bursting strength is measured at five locations on each net.

Wounded bursting strength test: In a variation of the test suggested by Smith et al.,[2] a net specimen receives a small cut, severing one side of one cell of the mesh. It is almost inevitable that an LLIN will suffer some kind of physical damage from snags, cuts or burns in normal use, which will weaken the netting sufficiently to make it more susceptible to subsequent damage. The aim of this test is to measure the strength of a lightly damaged net and the extent to which it differs from that of an undamaged net. During the WHO meeting in August 2013, the term "wounded bursting strength" was used for this measure.

The location of the cut in the wounded specimen depends on the structure of the net. Some nets have cell sides that are symmetrically equivalent, so that a cut may be made on any side, and only one cut location need be tested. For nets that have cell sides that are not symmetrically equivalent, a cut on one side might have a greater effect on net strength than a cut on a non-symmetrical side. For these nets, the test must be repeated for each non-equivalent cell side. For the nets tested in this study, no more than two cut locations were needed. Photomicrographs showing the location of cuts made to each net are reproduced in *Figure A3.9*.

FIGURE A3.9. Representative photomicrographs showing the locations of cuts used in the wounded bursting strength test



[2] Smith SC, Ballard JP, White TJ. Development of laboratory tests for the physical durability of long-lasting insecticidal nets (LLINs) (Abstract 913). Paper presented at the 61st Annual Meeting of the American Society of Tropical Medicine and Hygiene, Atlanta, Georgia, 13 November 2012. (http://www.abstractsonline.com/Plan/SSResults.aspx).

FIGURE A3.9. (Contd.2)
Representative photomicrographs showing the locations of cuts used in the wounded bursting strength test

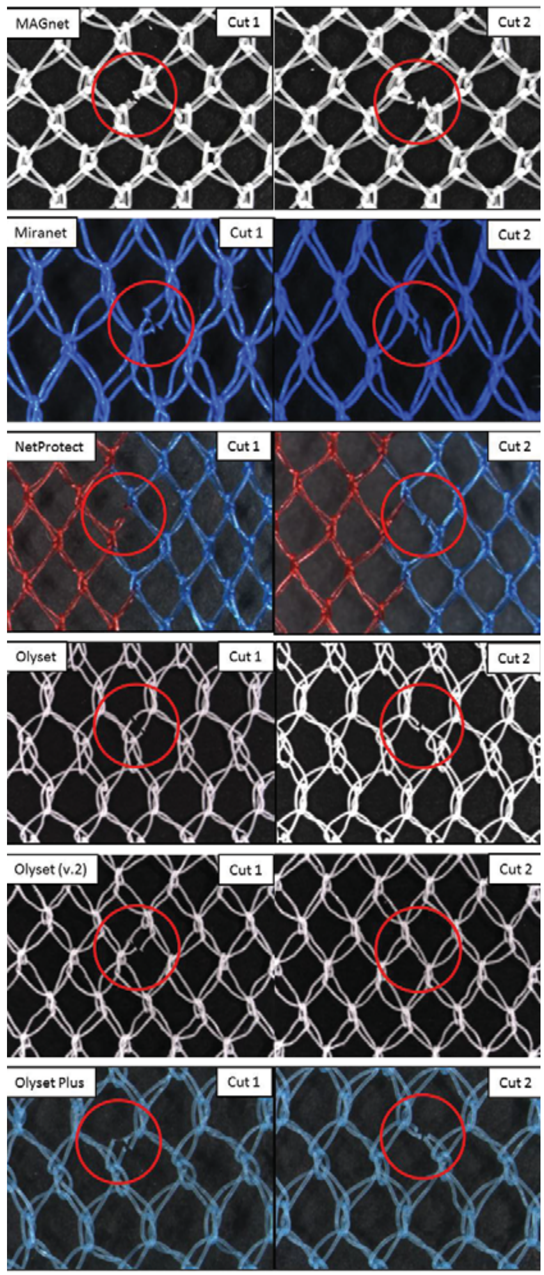


FIGURE A3.9. (Contd.3)
Representative photomicrographs showing the locations of cuts used in the wounded bursting strength test

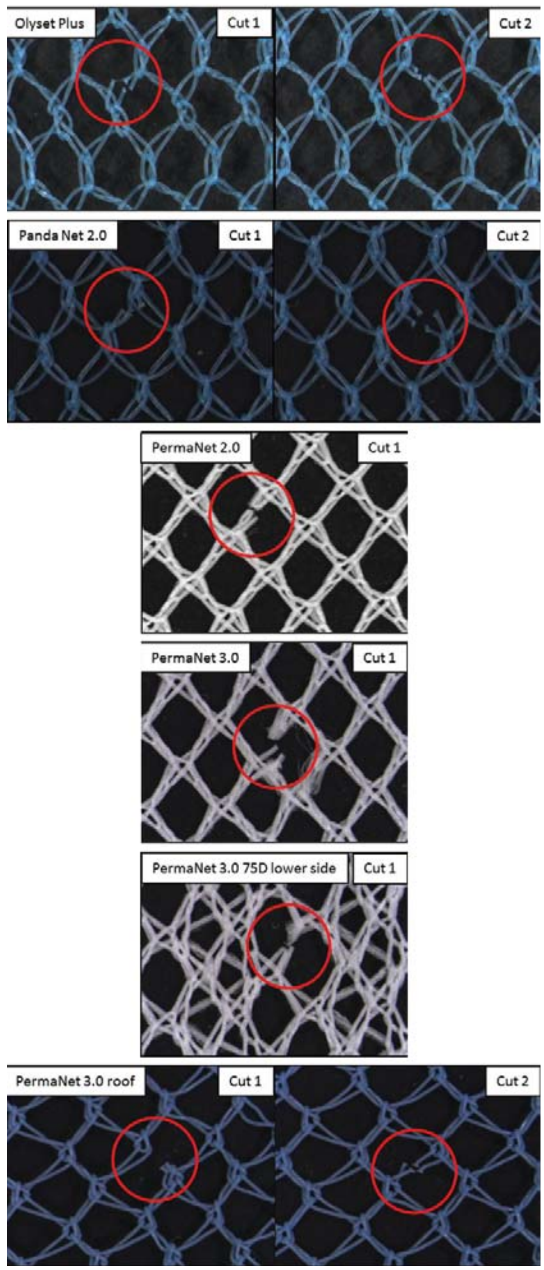
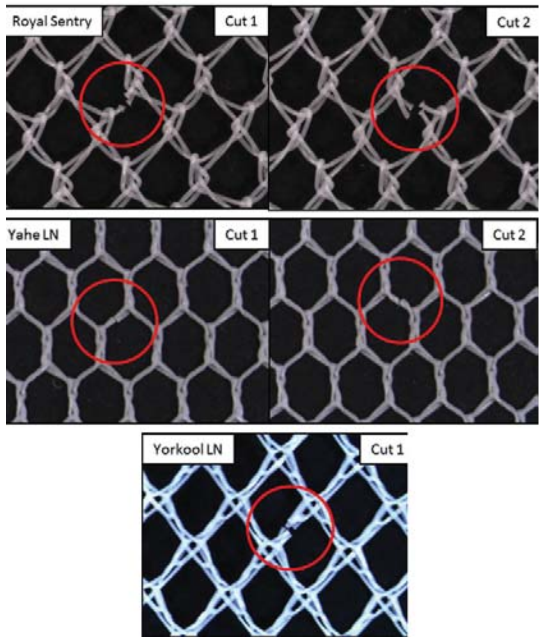


FIGURE A3.9. (Contd.4)
Representative photomicrographs showing the locations of cuts used in the wounded bursting strength test



TENSILE STRENGTH (METHOD EN ISO 13934-2)

The method used was EN ISO 13934-2, “standard grab and modified using hooks”. According to the ISO, this method is generally used for woven textiles but may also be applicable for other types of fabrics, but no guidance was found for evaluating the suitability of this test for fabrics such as lightweight, open warp knit mosquito netting.

The test measures the maximum force required to rupture a 100-mm specimen fixed in clamps set 100 mm apart and elongated uniaxially at a rate of 50 mm/min (*Figures A3.10* and *A3.11*). The clamp faces are designed so that there is a 25 × 25 mm clamping area at each end of the specimen. The term “grab” tensile refers to the fact that only a portion of the specimen width is clamped, in contrast to “strip” tensile in which the entire specimen width is clamped.

FIGURE A3.10. Grab tensile testing: beginning of test

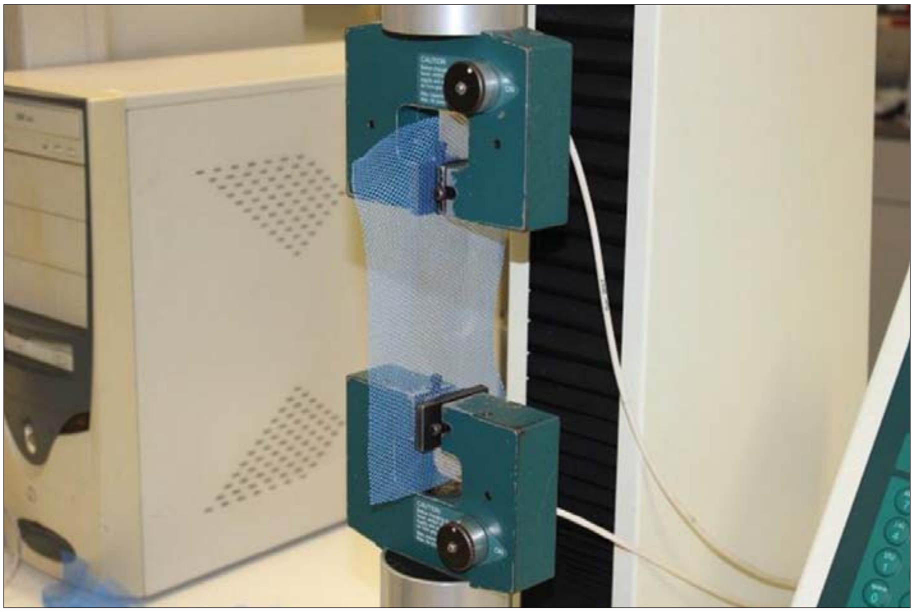
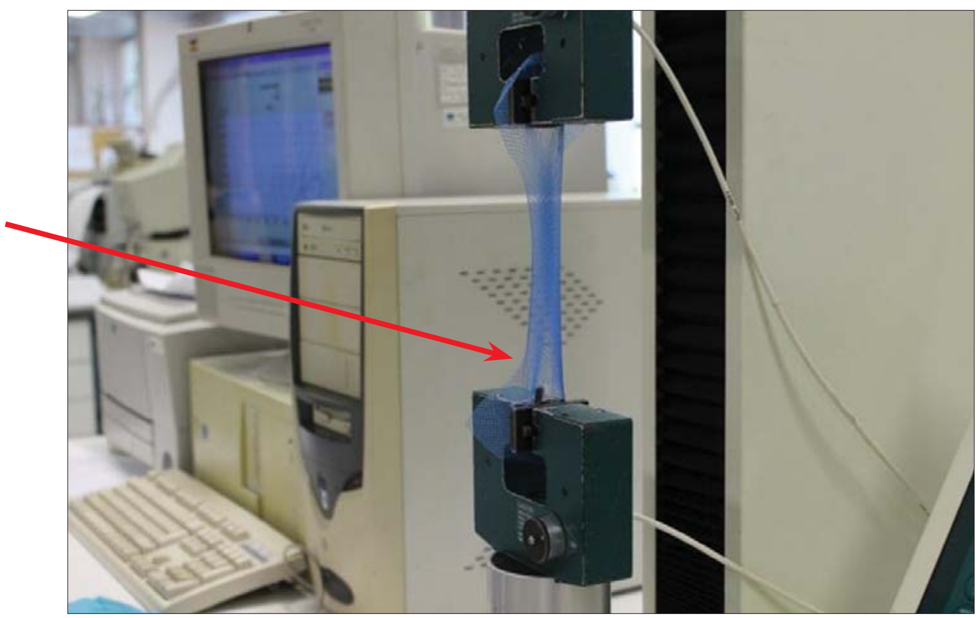


FIGURE A3.11. Grab tensile test: end of test, showing net rupture at clamp jaws



Skovmand and Bosselmann[1] described a variation of this test in which the clamps have metal hooks that pass through the netting mesh. This test, designated "hook" tensile in this document, is intended to simulate the stresses on netting when snagged by e.g. an exposed nail or tree branch. Each hook is a 1.6-mm diameter metal wire, bent at a 62° angle. A hook is attached to each end of the specimen (*Figures A3.12– A3.14*).

[1] Skovmand O, Bosselmann R. Strength of bed nets as function of denier, knitting pattern, texturizing and polymer. Malar J 2011;10:87.

As both these tests apply a uniaxial stress to the specimen, they must be conducted both along the warp ("length") and perpendicular to the warp ("width").

FIGURE A3.12. Hook tensile test: test apparatus showing hooks used to hold test specimen

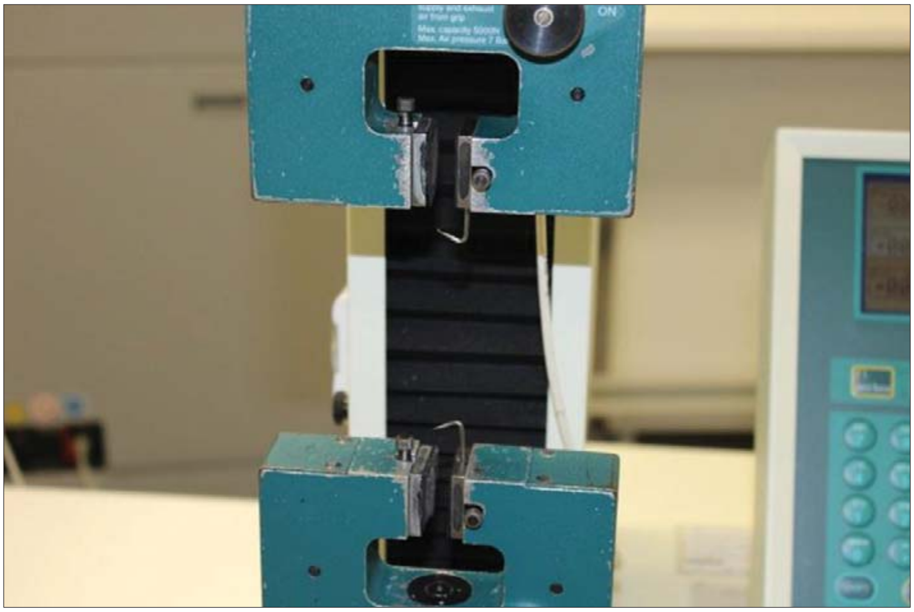


FIGURE A3.13. Hook tensile test: beginning of test

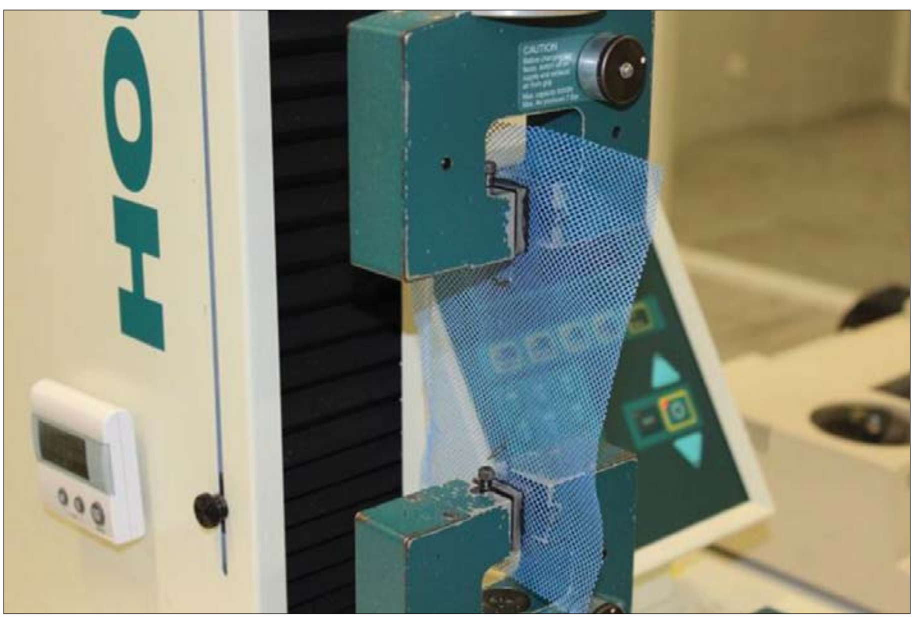
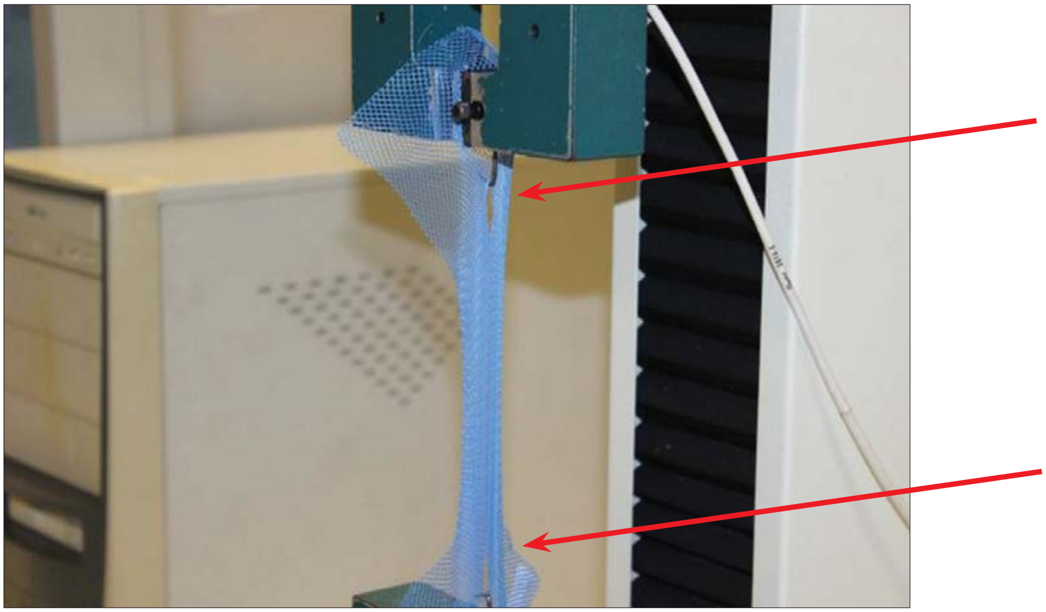


FIGURE A3.14. Hook tensile test: end of test, showing rupture of netting



TEAR RESISTANCE (METHOD EN ISO 13937-1; BALLISTIC PENDULUM, ELMENDORF TEAR)

As tearing is generally considered to be a significant cause of damage to LLINs, tear resistance could be one of the most important properties to be measured. Several standard tests have been developed. That used in this study is generally referred to as the “ballistic pendulum” or “Elmendorf tear” test. The test apparatus used in this study is shown in *Figures A3.15– A3.17*.

FIGURE A3.15. Ballistic pendulum (Elmendorf) tear resistance tester

FIGURE A3.16. Tear resistance tester with test specimen in clamps before testing

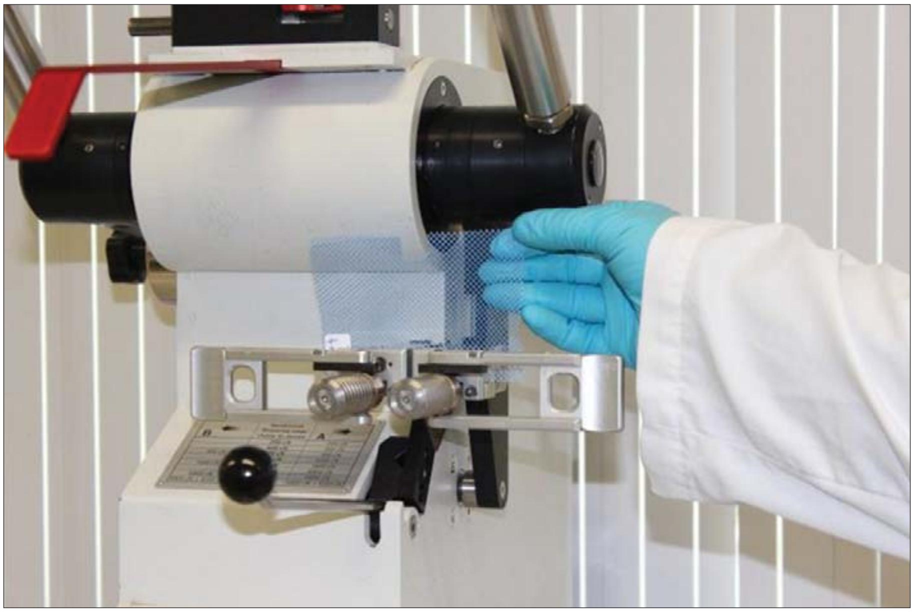


FIGURE A3.17. Tear resistance tester after testing, with torn specimen

In this test, a sudden force is applied to a pre-cut slit in the fabric, and the force required to propagate a tear is recorded. The test is done on five specimens each in the warp direction and perpendicular to the warp of the fabric. The test specimen is cut in the shape shown in *Figure A3.18*. A 20-mm slit is cut in the specimen, at which a tear is initiated. The objective is to produce a tear that terminates at the 15-mm notch on the opposite end of the sample. If the tear does not terminate at the notch, it is considered a "cross" tear. In the ISO method, the results for cross-tears are rejected; if three or more of five specimens (60%) exhibit cross-tears, the method is considered unsuitable for the test material. The ISO cautions that this test is not generally applicable to knitted fabrics, presumably because knitted structures are prone to cross-tearing. *Figure A3.19* shows two specimens, one with an acceptable tear and another with a cross-tear.

The ISO method states that additional specimens can be tested in order to reach consensus on the reporting and interpretation of results.

FIGURE A3.18. Diagram of tear resistance test specimen, showing examples of good and poor tearing behaviour

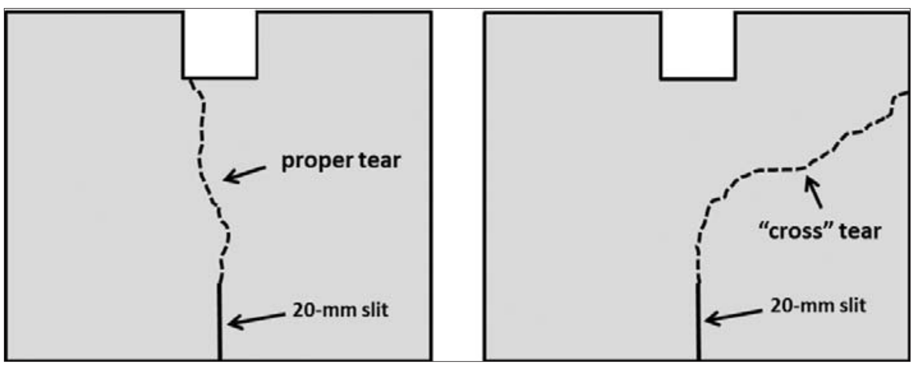
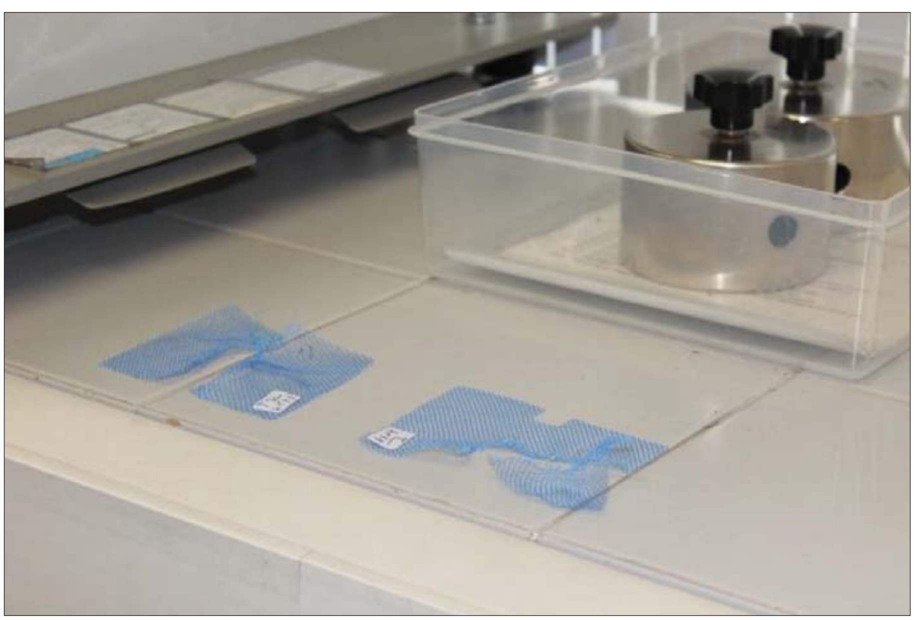


FIGURE A3.19. Test specimens showing acceptable tearing (left) and cross-tearing (right)



TEAR RESISTANCE (METHOD ISO 13937-2; TROUSER TEAR)

The trouser tear test is performed on a specimen cut as shown in *Figure A3.20*. The "legs" of the specimen are clamped in the jaws of a standard tensile testing machine (*Figure A3.21*), and the average force required to tear the specimen to a point 25 mm from the opposite edge is measured. The test is successful if there is no slippage of threads out of the fabric, no slippage in the jaws and the tear is complete and proceeds in the direction of the application of force.

As in the ballistic pendulum test, if three or more of five specimens are rejected for these reasons, the method is considered unsuitable.

FIGURE A3.20. Diagram of trouser tear test specimen

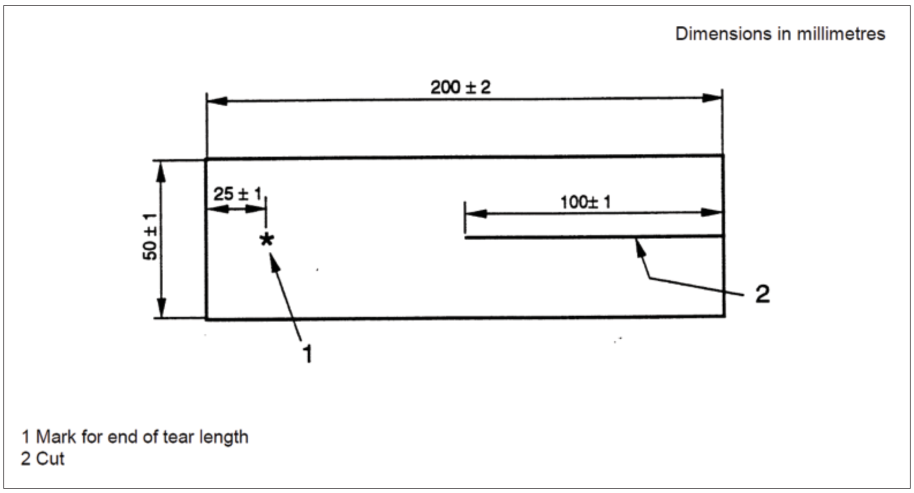
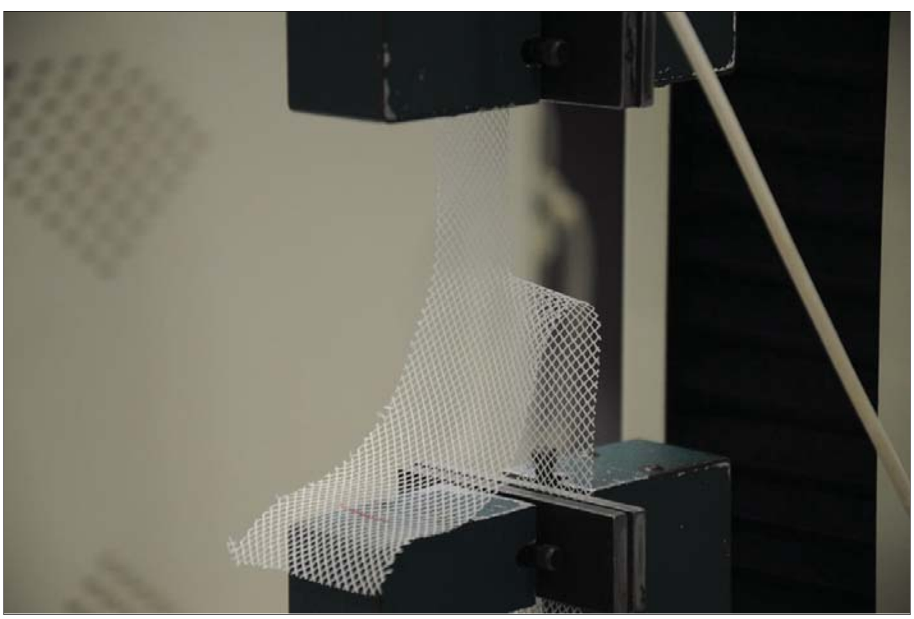


FIGURE A3.21. Trouser tear testing arrangement



TEAR RESISTANCE (METHOD ISO 13937-3; WING TEAR)

The specimen used in the wing tear test is cut as shown in *Figure A3.22*. As in the trouser tear method, the sample is mounted in a tensile testing machine (*Figures A3.23* and *A3.24*), and the average force required to tear the specimen is measured. The criteria for acceptable tears are the same as for the trouser tear method, and if three or more specimens are rejected the method is considered unsuitable.

FIGURE A3.22. Diagram of wing tear test specimen

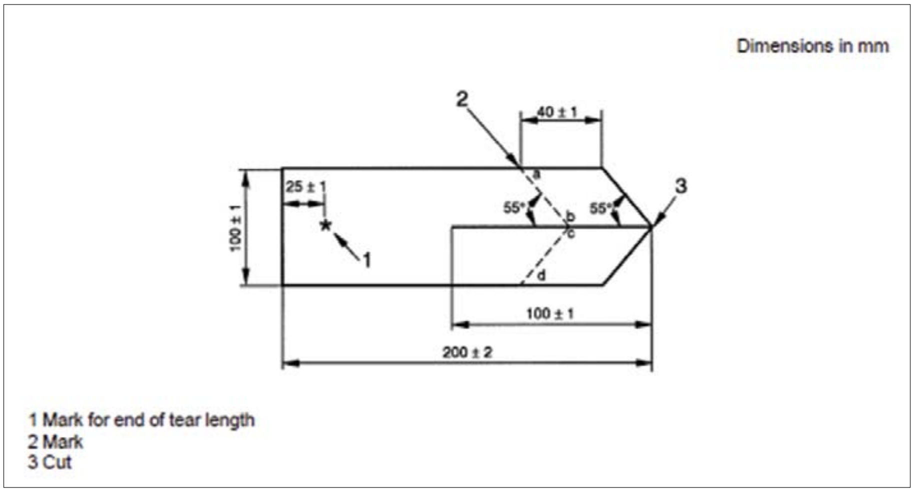


FIGURE A3.23. Wing tear testing arrangement

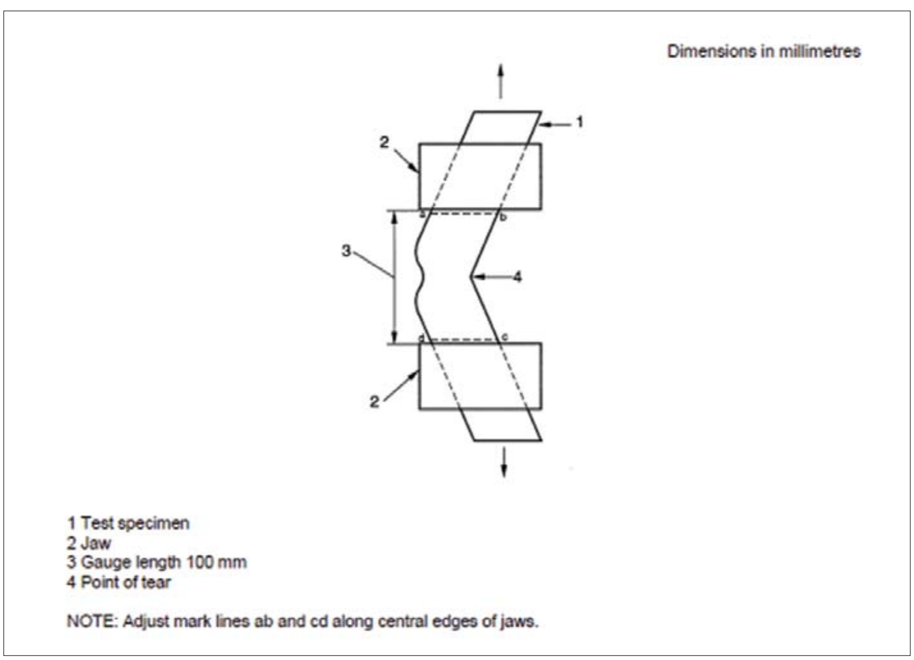
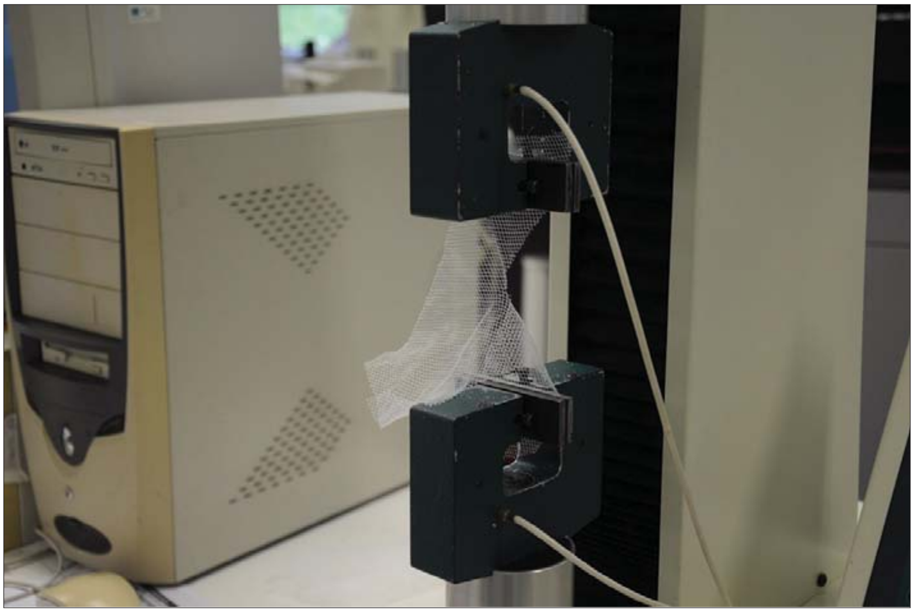


FIGURE A3.24. Wing tear test specimen mounted in tensile test machine



TEAR RESISTANCE (METHOD ISO 13937-4; TONGUE TEAR)

The specimen used in the tongue tear test is cut as shown in *Figures A3.25* and *A3.26*. As in the trouser tear method, the sample is mounted in a tensile testing machine (*Figure A3.27*), and the average force required to tear the specimen is measured. The criteria for acceptable tears are the same as for the trouser and wing tear methods, and if three or more specimens are rejected the method is considered unsuitable.

FIGURE A3.25. Diagram of tongue tear test specimen

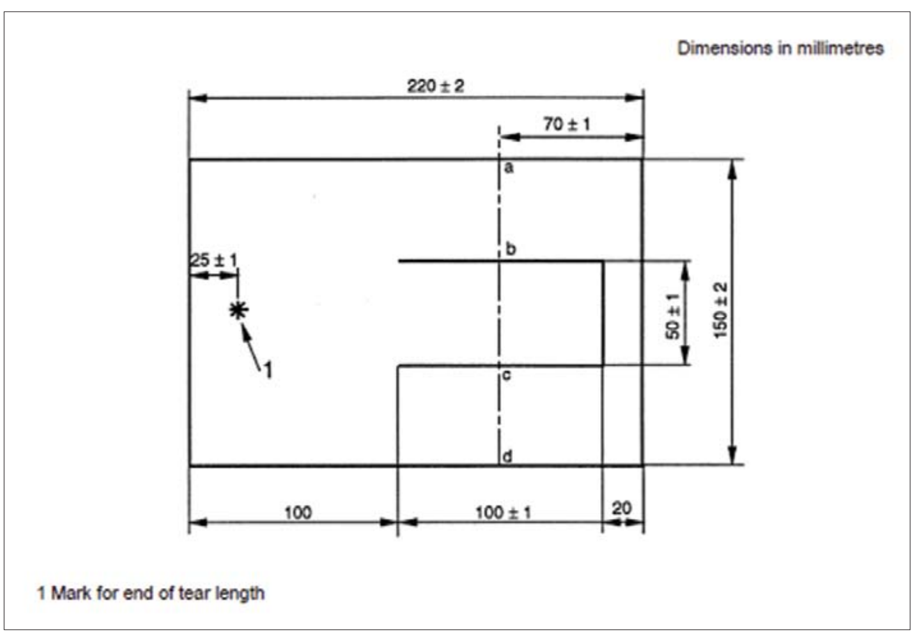


FIGURE A3.26. Tongue tear test specimens

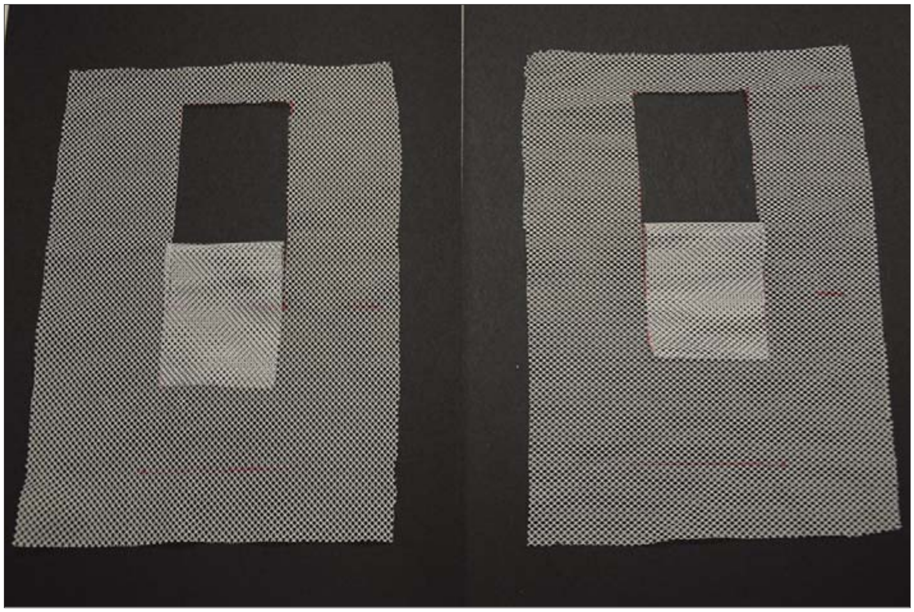
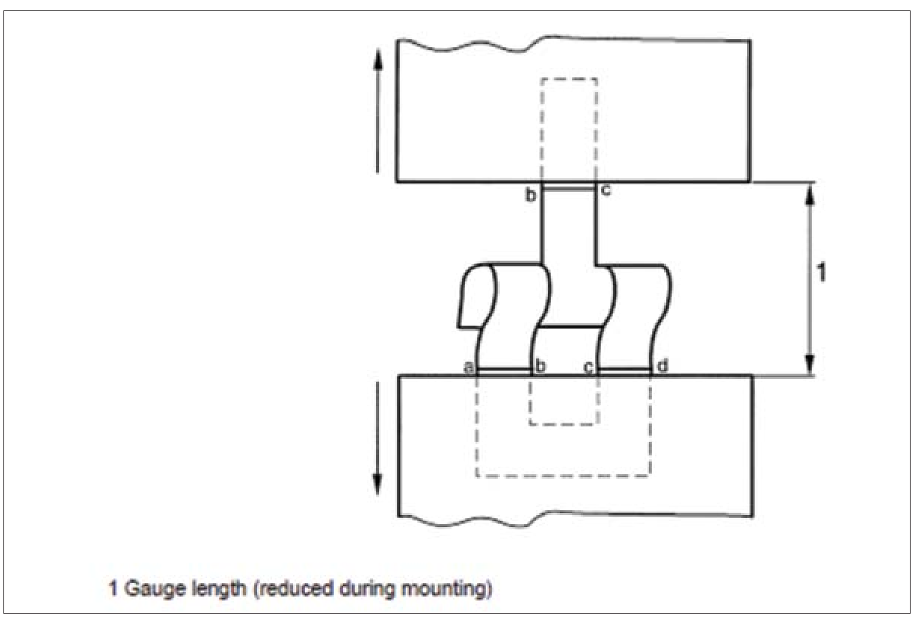


FIGURE A3.27. Tongue tear testing arrangement

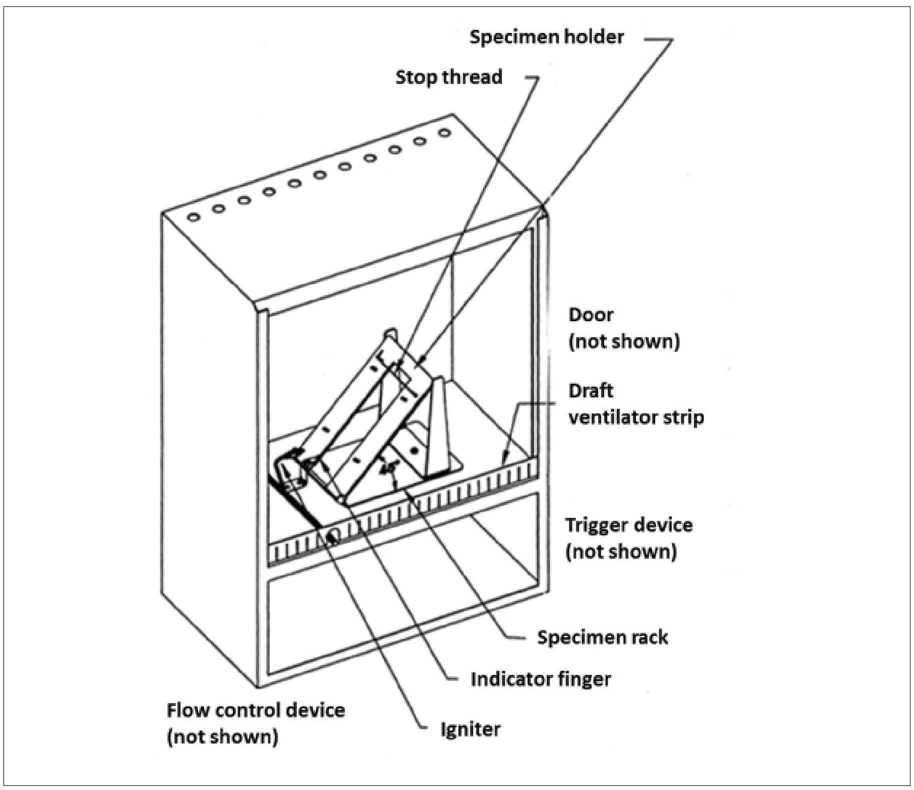


FLAMMABILITY (METHOD 16 CFR PART 1610)

In 2005, a WHO consultation recommended[1] that the flammability of nets be determined by the manufacturer according to method 16 CFR Part 1610.[2] The test was designed for textiles intended to be used for apparel and establishes three degrees of flammability: normal, intermediate and rapid and intense burning. LLINs are required to fall into Class 1 (normal category) in this test to receive WHOPES recommendation.

In this test, a specimen is mounted at a 45° angle in a test chamber (*Figures A3.28* and *A3.29*) in a frame that exposes a 38 × 152 mm area. A thread is placed across the upper end of the specimen 127 mm from the point at which a flame is applied. The flame is brought into contact with the top surface at the lower end of the specimen for 1 s. If it takes 3.5 s or longer for the flame to travel up the specimen and reach the stop thread, the specimen falls in to Class 1.

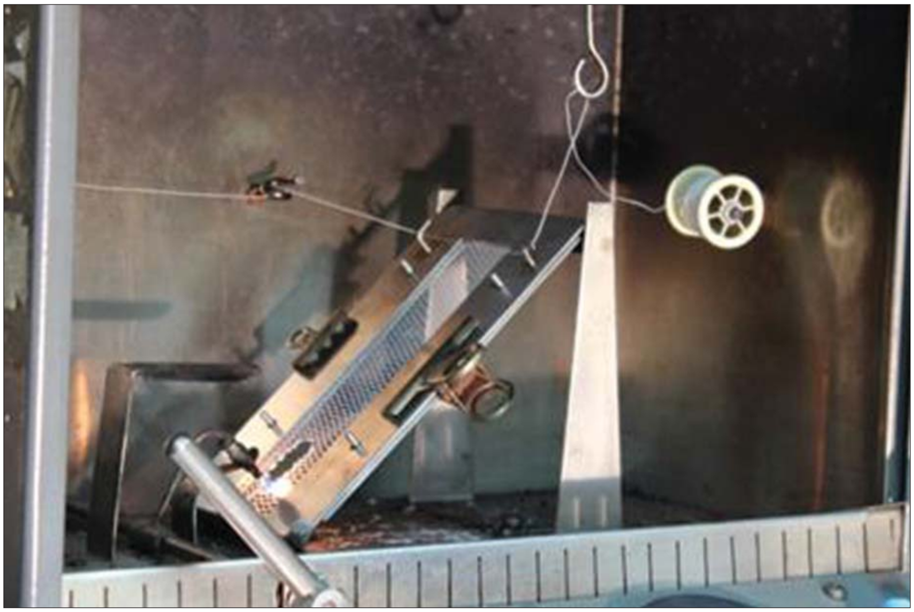
FIGURE A3.28. Diagram of flammability testing apparatus used in Method 16 CFR 1610



[1] Technical consultation on specifications and quality control of netting materials and mosquito nets. Geneva: World Health Organization; 2005 (http://www.who.int/malaria/publications/atoz/tech-consultnettingmaterials.pdf).

[2] Flammability is not included in the current WHO specifications for nets, but manufacturers are required to print the results of the 16 CFR Part 1610 test on net packaging. See: Manual on development and use of FAO and WHO specifications for pesticides. 2nd edition. Geneva/Rome: World Health Organization/Food and Agriculture Organization of the United Nations; 2010 (http://whqlibdoc.who.int/publications/2006/9251048576_eng_update3.pdf).

FIGURE A3.29. Flammability testing apparatus used in Method 16 CFR 1610



FLAMMABILITY (METHOD EN 1102)

This method is derived from ISO method 6941 for measuring the flammability of vertically oriented fabrics, such as curtains. Flammability test EN 1102 differs from the ISO method by including the observation of burning "behaviour", notably the dripping of burning melted polymer that is capable of igniting filter paper placed below the specimen.

A 560 × 170 mm test specimen is fixed vertically in a test frame (*Figure A3.30*), and a horizontal flame is brought into contact at a point 20 mm from the bottom edge of the specimen. As in the previous flammability test, threads are placed across the sample at 220 mm and 520 mm above the point of application of the flame. During the test, the flame is placed in contact with the specimen for 10 s and then removed. The time required for the flame to propagate to each of the marker threads is recorded. Also recorded is the occurrence of airborne flaming debris, after-flame time, filter paper ignition (from dripping, ignited polymer) and surface flash. Continued burning is recorded as either an open flame or a specimen-consuming afterglow. When burning ceases, the maximum length and width of the burnt area (hole) is measured. *Figures A3.31–A3.33* show an example of an ignited test specimen producing burning polymer drips.

FIGURE A3.30. Vertical flammability test apparatus used in Method EN 1102

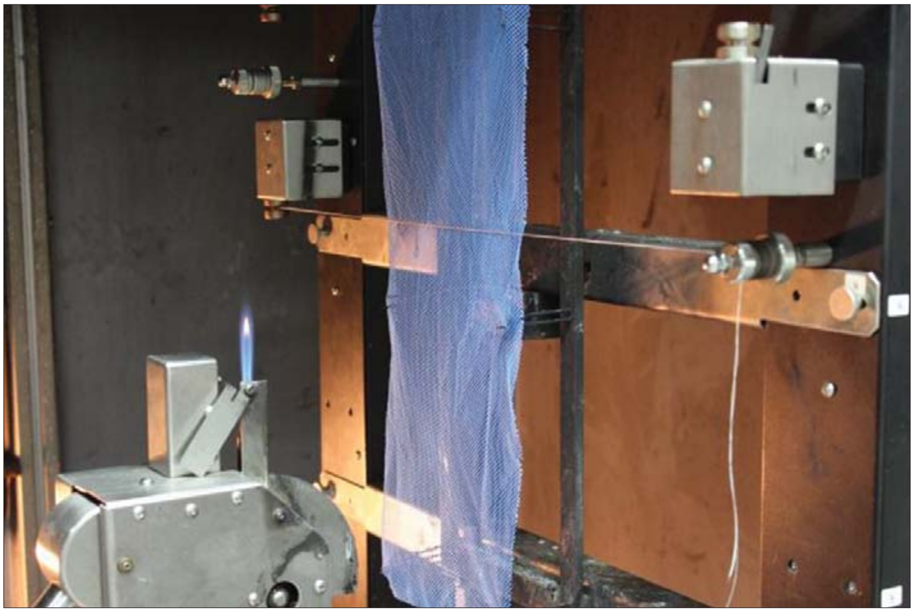


FIGURE A3.31. Test specimen ignited during vertical flammability testing in Method EN 1102

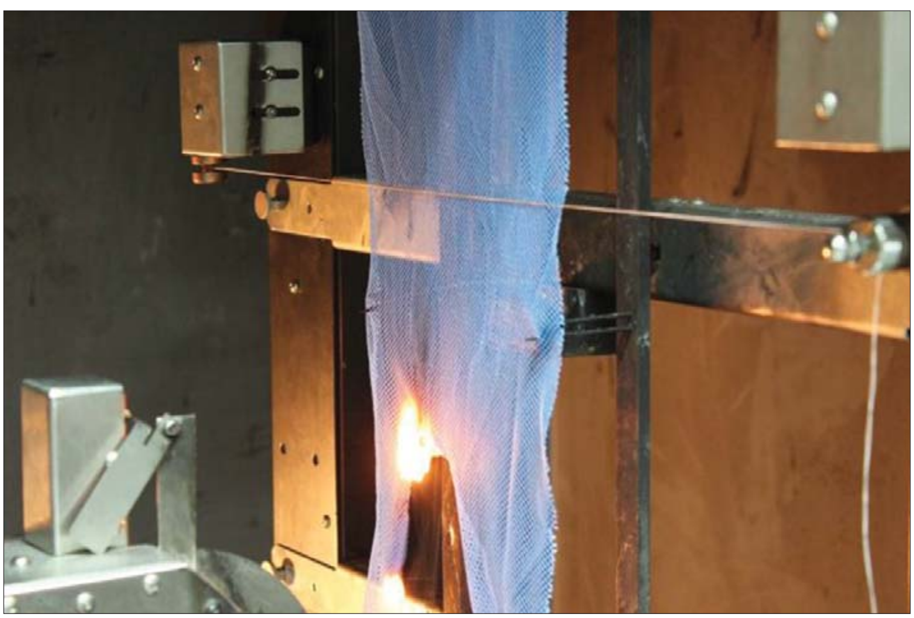


FIGURE A3.32. Test specimen dripping burning polymer melt during vertical flammability test in Method EN 1102

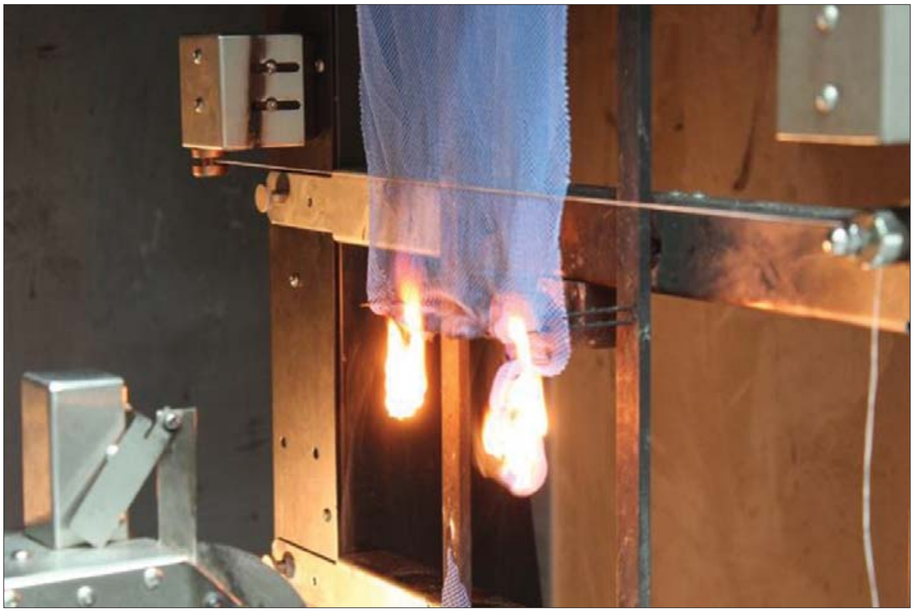


FIGURE A3.33. Paper ignited by burning polymer melt during vertical flammability test in Method EN 1102

RESULTS AND DISCUSSION

FABRIC WEIGHT

The results of tests for fabric weight are shown in *Table A3.2*, in which the results for all specimens of a given net brand are pooled. The fabric weights ranged from 30.6 to 49.8 g/m², with standard deviations of 0.3–2.6.

Table A3.2. Results of fabric weight measurements

LLIN	Panel	Fabric weight (g/m²)	
		Mean	Standard deviation
DawaPlus 2.0 75 denier		31	0.7
DawaPlus 2.0 100 denier		41.5	1.1
Duranet		49.8	2.1
Interceptor 75 denier		30.6	1.1
Interceptor 100 denier		42.1	1
LifeNet		45	1.9
Magnet		49.8	0.6
Miranet		44.8	1.4
NetProtect		41.5	2.3
Olyset Net		42.7	1.2
Olyset Net (v. 2)		41.1	1.6
Olyset Plus		42.5	1.5
Panda Net 2.0		45.4	2.6
PermaNet 2.0 75 denier		34	1.1
PermaNet 2.0 100 denier		40.9	0.8
PermaNet 3.0 75 denier	Upper part of side panel	32.3	0.6
	Lower part of side panel	44.1	0.7
	Roof	37.7	0.9
PermaNet 3.0 100 denier	Side panel	42.2	0.3
	Roof	36.2	1.1
Royal Sentry		47.2	2.6
Yahe		34.3	0.8
Yorkool 75 denier		32.6	0.9
Yorkool 100 denier		42	2.5

15 samples of each net were tested.

BURSTING STRENGTH

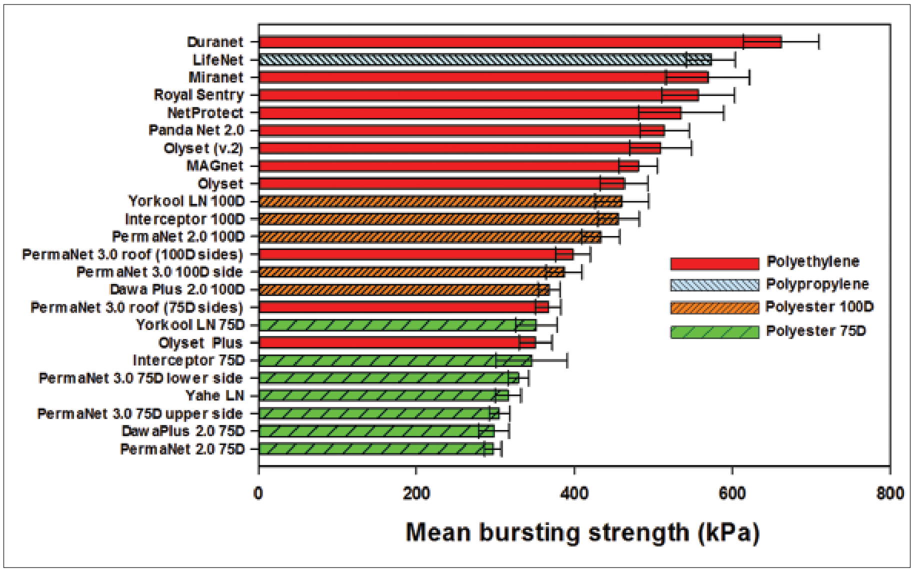
The bursting strengths of the netting and seams of each LLIN are listed in *Table A3.3*. For all specimens, the mean bursting strength exceeded the minimum of 250 kPa established by WHOPES. LLINs are ranked according to decreasing bursting strength of netting in *Figure A3.34*. It is notable that the nine highest-ranking LLINs were made of either polyethylene or polypropylene; all the remaining LLINs, with the exception of Olyset Plus and the PermaNet 3.0 roof net, were made of polyester.

Table A3.3. Results of bursting strength tests

LLIN	Panel	Bursting strength (kPa)											
		Netting						Seam					
		A	B	C	Mean	SD	95% CI	A	B	C	Mean	SD	95% CI
DawaPlus 2.0 75 denier		299	298	296	298	19	288–308	571	464	500	512	76	474–550
DawaPlus 2.0 100 denier		361	374	370	368	14	361–375	440	450	383	424	46	401–448
Duranet		675	667	646	662	48	638–687	737	705	731	724	61	694–755
Interceptor 75 denier		304	372	363	346	45	324–369	424	616	555	532	93	485–579
Interceptor 100 denier		459	429	478	456	26	443–469	889	668	525	694	172	607–781
LifeNet		593	565	563	573	31	558–589	682	714	731	709	41	688–730
MAGnet		489	484	470	481	24	469–493	648	682	711	680	101	629–732
Miranet		568	591	548	569	53	542–596	688	687	646	674	96	625–723
Netprotect		547	549	509	535	54	508–562	622	716	535	624	97	575–673
Olyset Net		479	452	458	463	30	448–478	593	575	571	580	93	533–627
Olyset Net (v.2)		513	496	520	509	39	490–529	652	717	677	682	71	646–718
Olyset Plus		352	343	358	351	21	340–362	517	515	551	528	79	487–568
Panda Net 2.0		519	502	521	514	31	498–530	554	536	638	576	119	516–636
PermaNet 2.0 75 denier		302	293	295	297	11	291–303	434	435	475	448	73	411–485
PermaNet 2.0 100 denier		422	449	429	434	24	422–446	667	607	622	632	120	571–693
PermaNet 3.0 75 denier	Upper sick	293	314	308	305	13	298–312	444	441	447	444	41	423–465
	Lower sick	334	319	334	329	13	322–336	–	–	–	–	–	–
	Roof	378	350	374	367	16	359–375	–	–	–	–	–	–
PermaNet 3.0 100 denier	Sick	373	394	393	387	23	375–399	536	591	598	575	92	528–622
	Roof	395	413	387	398	22	387–409	–	–	–	–	–	–
Royal Sentry		519	565	587	557	46	533–580	673	674	761	703	76	664–741
Yahe 75 denier		321	305	321	316	16	308–324	455	413	365	411	89	366–456
Yorkool 75 denier		354	371	331	352	26	339–365	522	446	552	507	71	471–542
Yorkool 100 denier		472	438	472	460	34	443–478	774	453	583	603	143	531–675

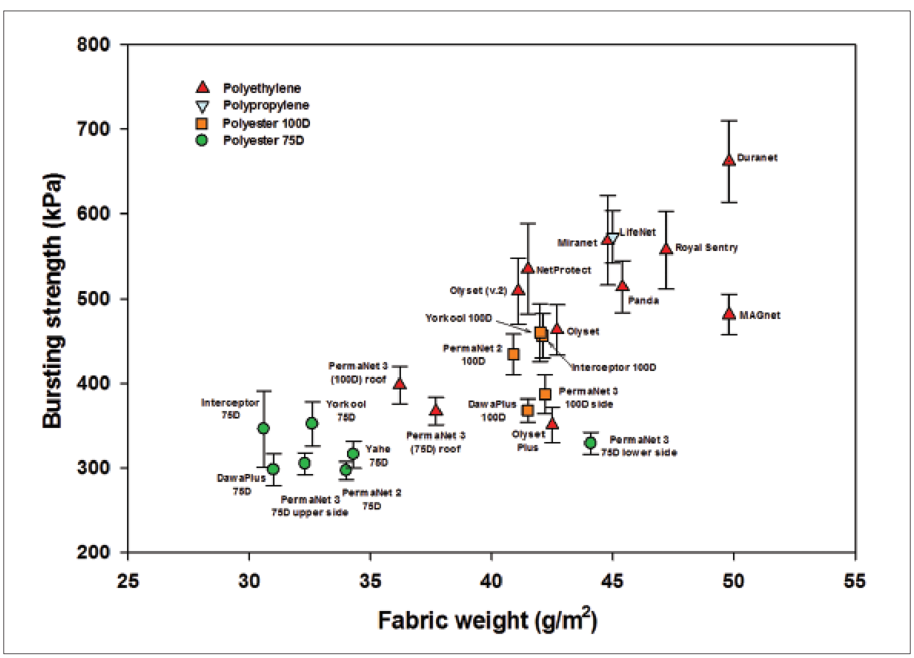
A, B and C = three LLINs of each brand were tested; values given represent a mean of five tests per net.
Means, standard deviations and confidence intervals were calculated for the combined results for all three nets (n = 15)
SD = standard deviation

FIGURE A3.34. Ranking of bursting strength of nets tested



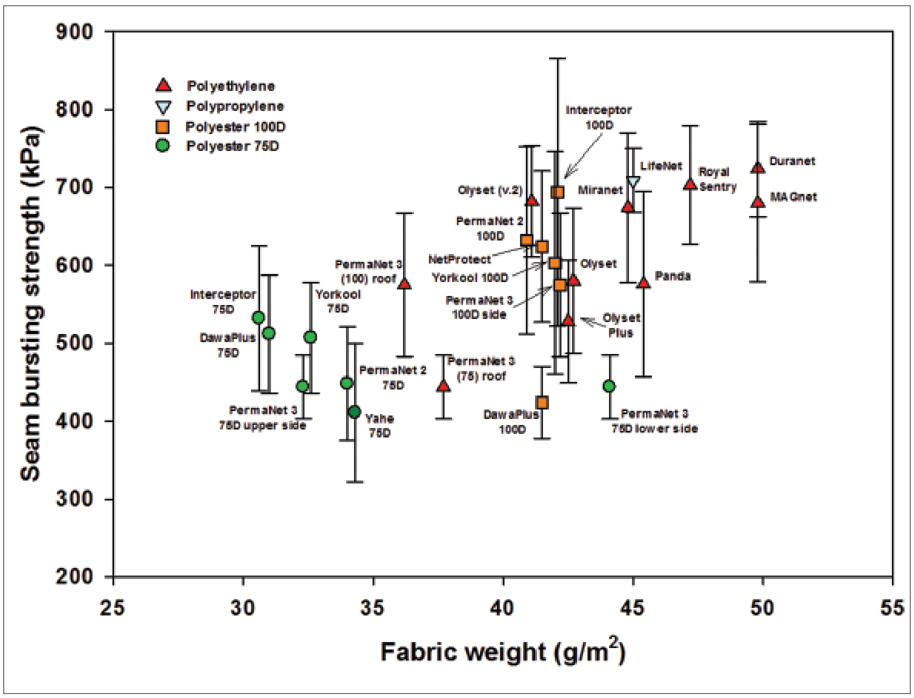
The relation between the bursting strength of netting and fabric weight is shown in *Figure A3.35*. In general, bursting strength increased with fabric weight, although the correlation was not perfect. Other variables, including yarn tenacity, denier, knitting pattern and run-in (metres of yarn per m^2 of fabric), can also be expected to play a role in determining bursting strength.

FIGURE A3.35. Relation between bursting strength and fabric weight



The relation between the bursting strength of seams and fabric weight is shown in *Figure A3.36*. The correlation was not as close as for netting alone, probably due to the confounding effect of the seam structure and the type of thread used. In all cases, however, the seam bursting strengths were well above the 250-kPa minimum specified by WHOPES.

FIGURE A3.36. Relation between seam bursting strength and fabric weight



As might be expected, the bursting strengths of wounded samples were much lower than those of the corresponding intact samples (*Table A3.4*). *Figure A3.37* shows the ranking of the nets according to decreasing wounded bursting strength. The polyethylene monofilament nets with the highest unwounded bursting strengths had some of the lowest wounded bursting strengths. As a group, the polyethylene monofilament nets lost 70–81% of their bursting strength when wounded, while the remaining nets lost 28–44%. *Figures A3.38* and *A3.39* show the bursting strengths of intact and wounded samples of each net.

Table A3.4. Results of wounded bursting strength tests

LLIN	Panel	Wounded bursting strength (kPa)											
		Cut 1						Cut 2					
		A	B	C	Mean	SD	95% CI	A	B	C	Mean	SD	95% CI
DawaPlus 2.0 75 denier		224	187	222	211	27	197–225	–	–	–	–	–	–
DawaPlus 2.0 100 denier		233	216	231	227	20	217–237	–	–	–	–	–	–
Duranet		130	128	115	124	19	114–134	163	173	168	168	26	155–181
Interceptor 75 denier		253	243	211	236	29	221–251	–	–	–	–	–	–
Interceptor 100 denier		260	300	282	281	30	266–296	–	–	–	–	–	–
LifeNet		330	336	339	335	34	318–352	–	–	–	–	–	–
MAGnet		125	117	102	115	15	107–123	195	197	180	191	14	184–198
Miranet		163	173	154	163	17	154–172	162	170	173	168	16	160–176
Netprotect		123	121	101	115	19	105–125	176	150	144	157	32	141–173
Olyset Net		103	104	116	108	15	100–116	126	128	132	128	15	120–136
Olyset Net (v.2)		123	138	127	129	13	122–136	143	140	139	141	12	135–147
Olyset Plus		96	112	110	106	14	99–113	123	114	114	117	23	105–129
Panda Net 2.0		117	148	136	134	28	120–148	167	157	168	164	20	154–174
PermaNet 2.0 75 denier		171	174	194	180	26	167–193	–	–	–	–	–	–
PermaNet 2.0 100 denier		354	309	270	311	47	287–335	–	–	–	–	–	–
PermaNet 3.0 75 denier	Upper sick	184	188	171	181	21	170–192	–	–	–	–	–	–
	Lower sick	223	218	203	215	19	205–225	–	–	–	–	–	–
	Roof	77	70	70	72	14	65–79	158	164	160	161	16	153–169
PermaNet 3.0 100 denier	Sick	225	251	247	241	28	227–255	–	–	–	–	–	–
	Roof	76	76	78	77	14	70–84	146	138	141	142	24	130–154
Royal Sentry		155	156	134	148	27	134–162	163	164	180	169	29	154–184
Yahe 75 denier		233	193	187	205	38	186–224	237	218	208	221	21	210–232
Yorkool 75 denier		266	237	220	241	29	226–256	–	–	–	–	–	–
Yorkool 100 denier		276	246	270	264	34	246–281	–	–	–	–	–	–

A, B and C = three LLINs of each brand were tested; values given represent a mean of five tests per net. Means, standard deviations and confidence intervals were calculated for the combined results for all three nets (n = 15)
Cut 2 = a second cut was made to evaluate wounded bursting strength for nets with asymmetrical cell sides (see text on wounded bursting strength methods)
N = Newton (standard unit of force); SD = standard deviation

FIGURE A3.37. Ranking of wounded bursting strength of nets tested

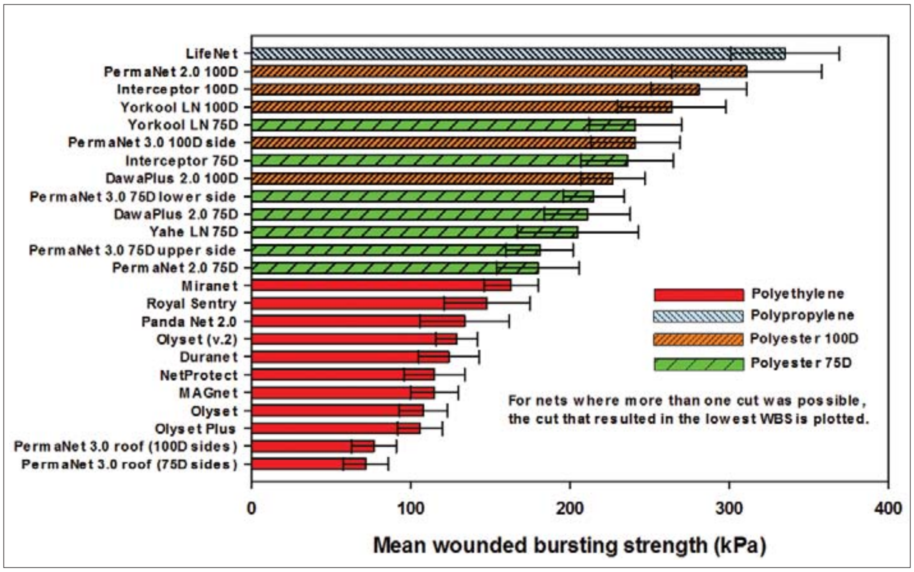


FIGURE A3.38. Relation between bursting strength and wounded bursting strengths of nets tested

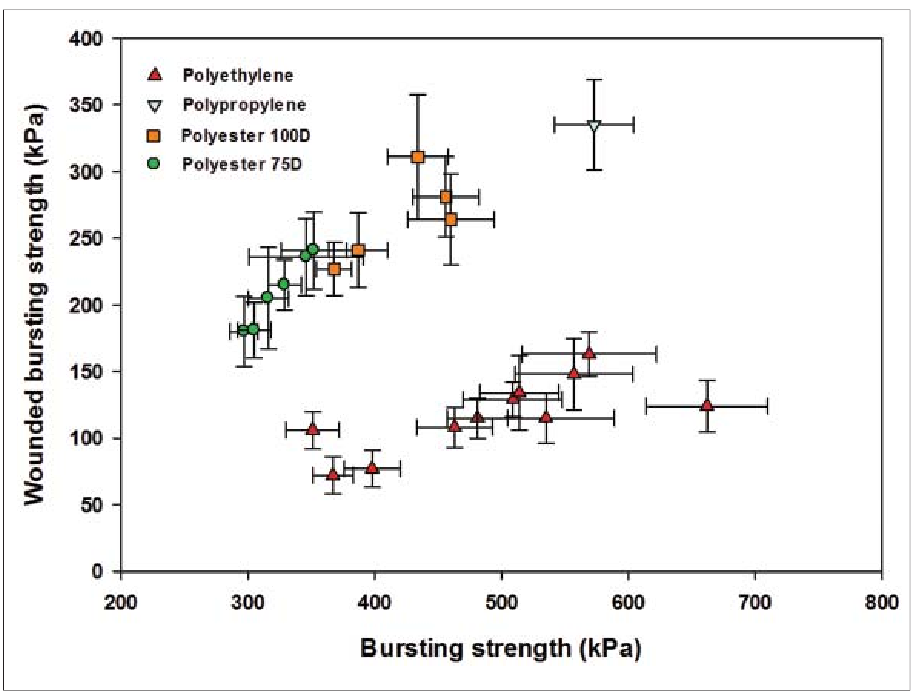
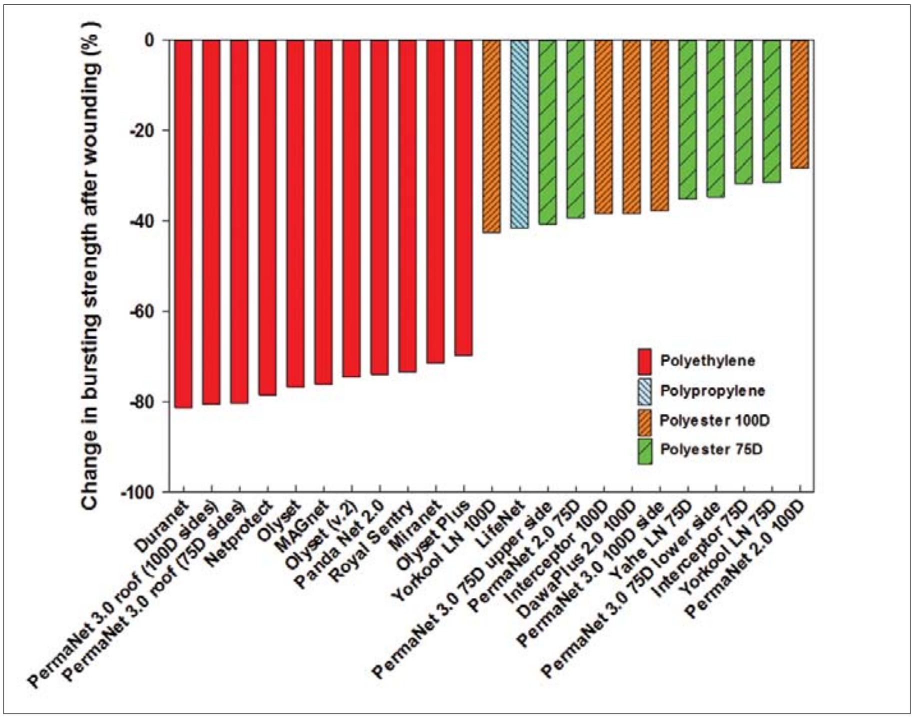


FIGURE A3.39. Change in bursting strength after wounding



TENSILE STRENGTH

The results for grab tensile strength are listed in *Table A3.5*. In every specimen, rupture occurred at the point at which it was clamped. These "jaw breaks" must be interpreted with care, as the clamping pressure, stresses due to specimen necking-in and the physical characteristics of the jaw faces could influence the results. In such cases, the ISO 13439-2 method states:

> *If all the results are jaw breaks, or if five "normal" breaks cannot be obtained then the individual results shall be reported without the coefficient of variation or confidence limits. Jaw break results shall be indicated as such in the report, and the results discussed between the interested parties.*

Figure A3.40 shows a ranking of the LLINs according to descending grab tensile strength in the length direction.
The tensile strength values in the hook test (*Table A3.6*) were substantially lower than those in the grab test, as the hooks concentrate the applied force onto a smaller area of the specimen, and less force is necessary to cause a rupture. The LLINs are ranked according to descending hook tensile strength (length direction) in *Figure A3.41*.

Table A3.5. Results of grab tensile strength tests

LLIN	Panel	Grab tensile force (N)											
		Length direction						Width direction					
		A	B	C	Mean	SD	95% CI	A	B	C	Mean	SD	95% CI
DawaPlus 2.0 75 denier		130	140	130	132	10	127–137	59	63	69	64	5	61–66
DawaPlus 2.0 100 denier		180	180	180	176	6	173–179	110	110	110	112	7	108–115
Duranet		320	300	320	312	16	304–320	210	220	200	215	12	208–221
Interceptor 75 denier		140	170	150	153	19	143–162	76	95	91	87	11	82–93
Interceptor 100 denier		210	230	230	224	13	217–231	120	110	110	116	10	111–121
LifeNet		270	260	260	262	18	253–271	180	180	160	173	12	167–179
MAGnet		250	240	260	251	16	242-259	190	180	180	183	14	176–190
Miranet		240	220	240	230	20	224–244	110	110	120	120	15	110–125
Netprotect		280	250	250	261	28	246-275	150	170	150	156	15	148–164
Olyset Net		240	260	230	240	18	230–249	110	96	100	102	9	98–107
Olyset Net (v.2)		220	240	220	229	26	216–242	130	110	120	120	12	114–126
Olyset Plus		170	180	170	171	12	165-177	94	94	93	94	6	91–97
Panda Net 2.0		240	210	230	230	18	218–236	140	120	130	130	11	124–135
PermaNet 2.0 75 denier		120	120	120	120	6	120–126	86	80	76	81	7	77–84
PermaNet 2.0 100 denier		160	160	150	160	10	152-162	84	87	89	87	6	84–90
PermaNet 3.0 75 denier	Upper sick	110	120	130	120	10	115–125	68	70	78	72	6	69–75
	Lower sick	140	140	140	140	5	139–144	80	82	93	85	7	81–88
	Roof	140	140	170	150	17	143–161	150	140	170	160	14	148–162
PermaNet 3.0 100 denier	Sick	180	170	190	180	9	175–185	95	88	96	93	6	90–96
	Roof	150	150	170	160	11	149–160	160	130	140	150	15	137–152
Royal Sentry		260	240	230	242	29	228-256	170	160	170	169	9	164–173
Yahe 75 denier		130	120	160	140	18	127-145	64	45	52	54	9	49–58
Yorkool 75 denier		120	140	120	129	18	119–138	95	100	90	96	9	92–100
Yorkool 100 denier		190	190	180	187	24	175–200	110	140	130	127	19	117–137

All breaks occurred at the clamp (i.e. jaw breaks).

A, B and C = three LLINs of each brand were tested; values given represent a mean of five tests per net. Means, standard deviations and confidence intervals were calculated for the combined results for all three nets (n = 15); N = Newton (standard unit of force); SD = standard deviation

Table A3.6. Results of hook tensile strength tests

LLIN	Panel	Grab tensile force (N)											
		Length direction						Width direction					
		A	B	C	Mean	SD	95% CI	A	B	C	Mean	SD	95% CI
DawaPlus 2.0 75 denier		16	16	16	16	1	16–17	15	14	15	15	1	14–15
DawaPlus 2.0 100 denier		23	19	22	21	4	19–23	23	24	20	22	2	21–23
Duranet		74	72	64	70	10	65–75	56	52	52	53	5	51–56
Interceptor 75 denier		22	19	19	20	3	18–22	16	19	20	18	2	17–19
Interceptor 100 denier		24	25	27	25	6	22–28	21	21	22	21	2	20–22
LifeNet		36	34	36	35	6	32–38	35	34	33	34	2	33–35
MAGnet		63	66	54	61	9	56–66	47	52	47	49	4	47–51
Miranet		100	83	100	95	17	87–103	31	29	30	30	2	29–31
Netprotect		56	71	44	57	13	50–64	34	44	35	38	5	35–40
Olyset Net		54	69	57	60	11	54–66	28	33	29	30	4	28–32
Olyset Net (v.2)		67	62	69	66	7	62–70	31	34	32	32	4	30–35
Olyset Plus		44	45	43	44	5	42–46	22	24	25	24	3	22–25
Panda Net 2.0		66	66	76	69	14	62–77	41	33	40	38	5	36–41
PermaNet 2.0 75 denier		19	17	16	17	3	16–19	14	14	16	15	1	14–15
PermaNet 2.0 100 denier		24	23	23	23	3	22–25	20	19	20	20	2	19–21
PermaNet 3.0 75 denier	Upper side	19	18	21	19	3	18–21	16	16	15	16	1	15–17
	Lower side	22	19	22	21	4	19–23	17	17	16	17	2	16–18
	Roof	24	27	24	25	4	23–27	44	53	54	50	10	46–55
PermaNet 3.0 100 denier	Side	26	23	23	24	6	21–27	21	20	20	20	2	19–21
	Roof	21	31	27	26	5	24–29	50	49	42	47	8	43–51
Royal Sentry		49	62	63	58	10	53–63	42	40	56	46	9	41–51
Yahe 75 denier		43	53	47	48	8	44–52	21	18	17	19	3	17–20
Yorkool 75 denier		20	21	18	20	4	18–22	17	19	16	17	2	16–18
Yorkool 100 denier		35	24	22	27	7	23–31	21	23	24	23	3	21–24

A, B and C = three LLINs of each brand were tested; values given represent a mean of five tests per net. Means, standard deviations and confidence intervals were calculated for the combined results for all three nets (n = 15); N = Newton (standard unit of force); SD = standard deviation

FIGURE A3.40. Ranking of nets according to decreasing grab tensile strength in length direction

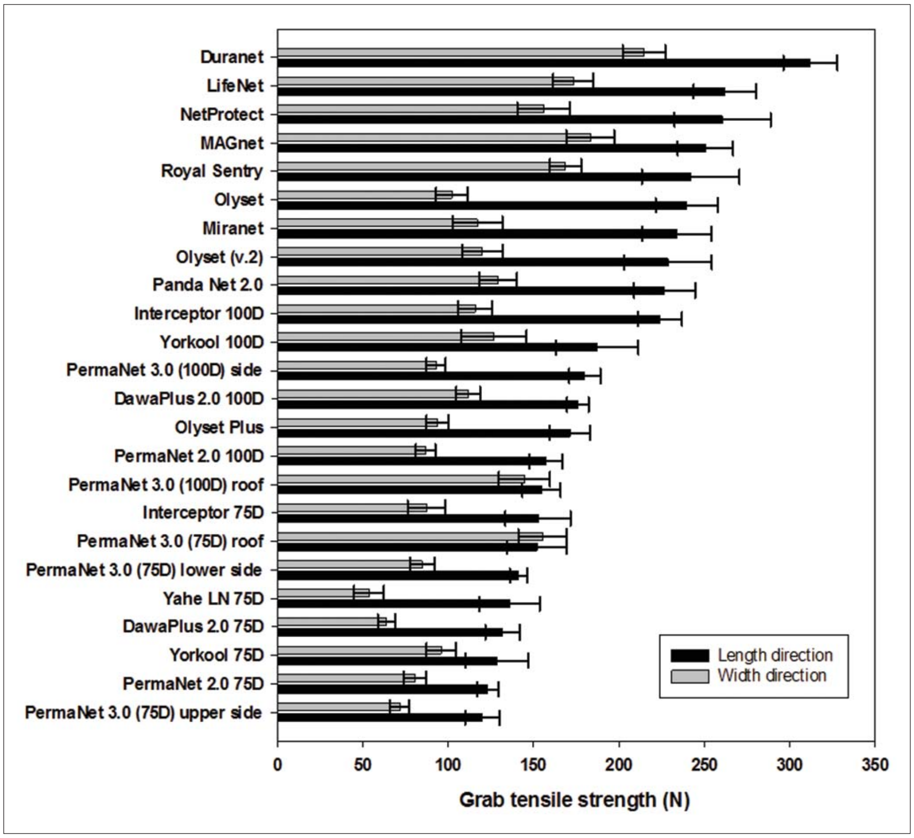
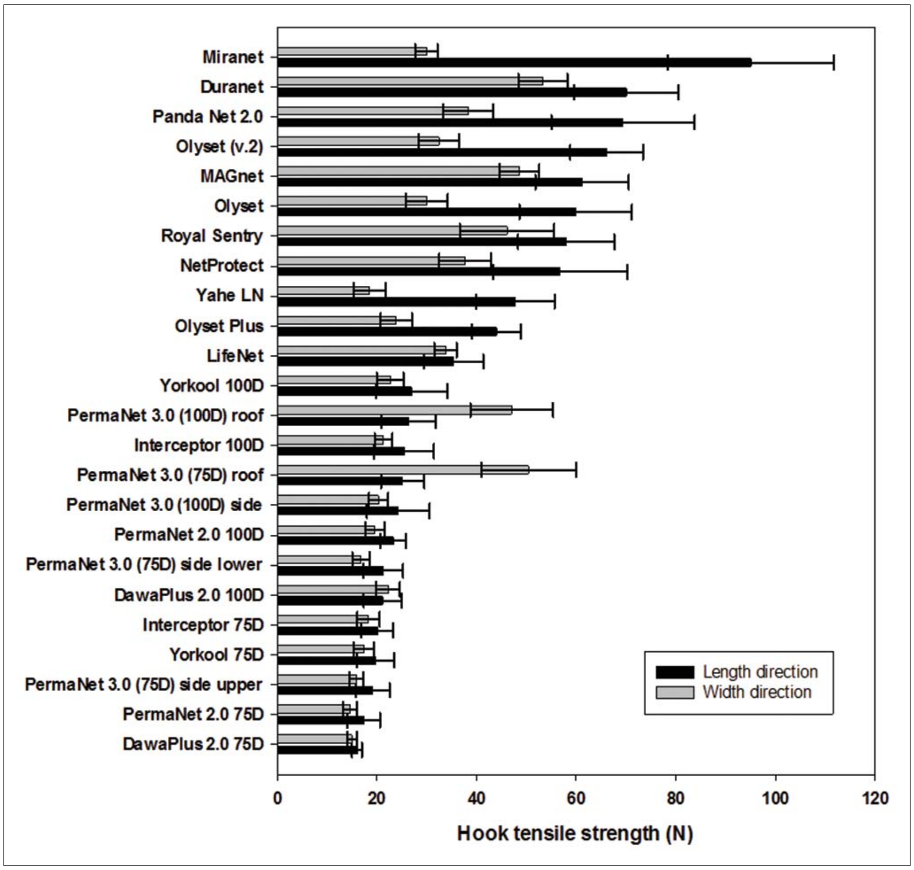


FIGURE A3.41. Ranking of nets according to decreasing hook tensile strength in length direction



A correlation can be seen between the results for grab and hook tensile strength (*Figures A3.42* and *A3.43*), especially in tests conducted in the width direction, for which the results fit a linear regression curve with an r^2 value of 0.8036.

A correlation might be expected between the bursting strength and the tensile strength in the weaker direction because the radial stress applied in the bursting strength test would result in a rupture in the weakest direction of the net. This correlation is shown in *Figure A3.44*.

FIGURE A3.42. Comparison of grab and hook tensile strength, length direction

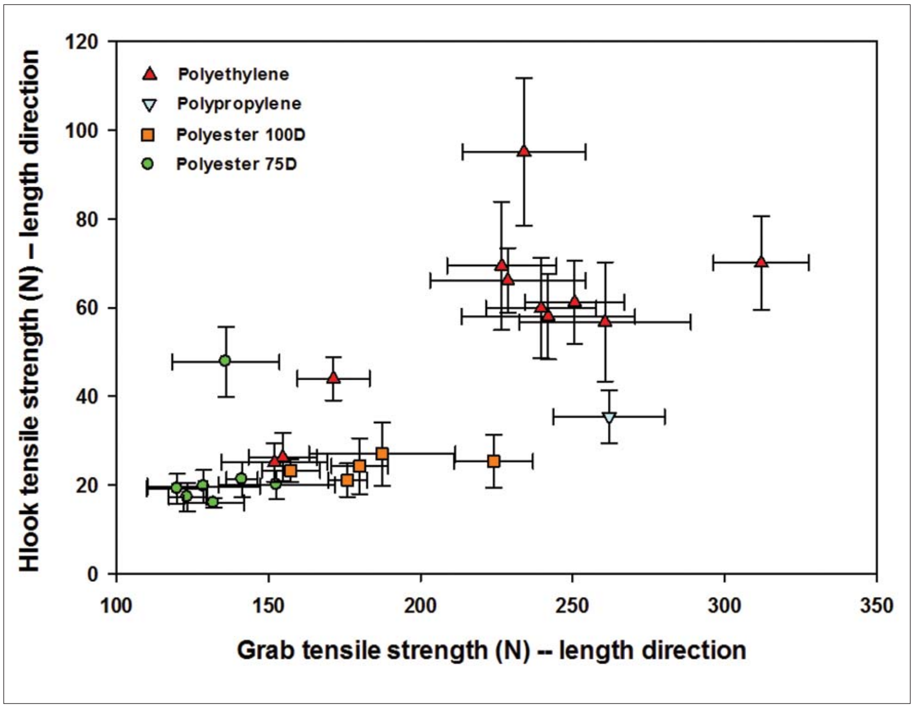


FIGURE A3.43. Comparison of grab and hook tensile strength, width direction

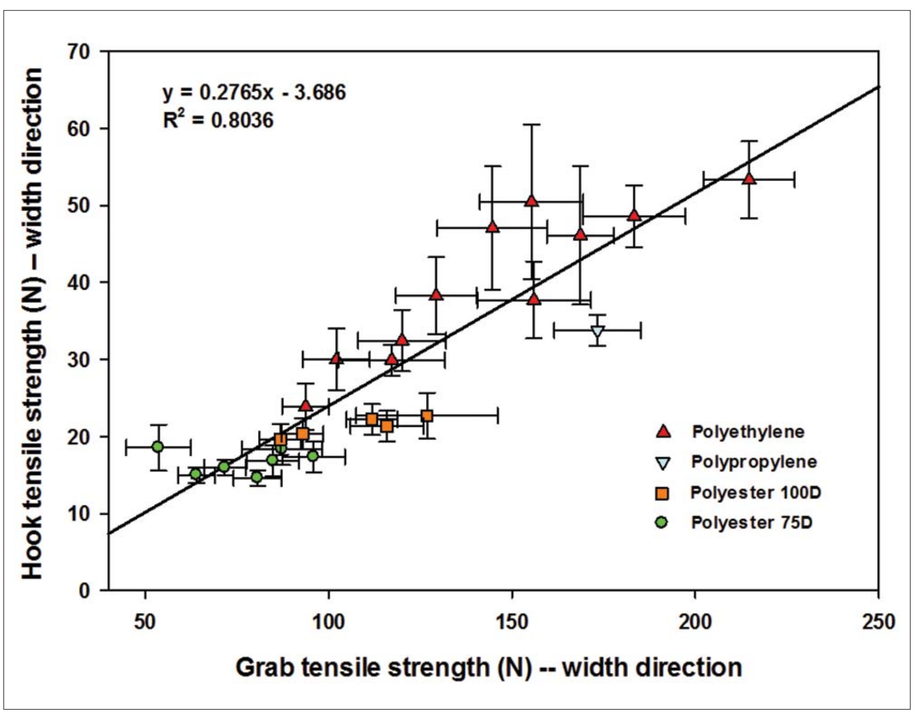
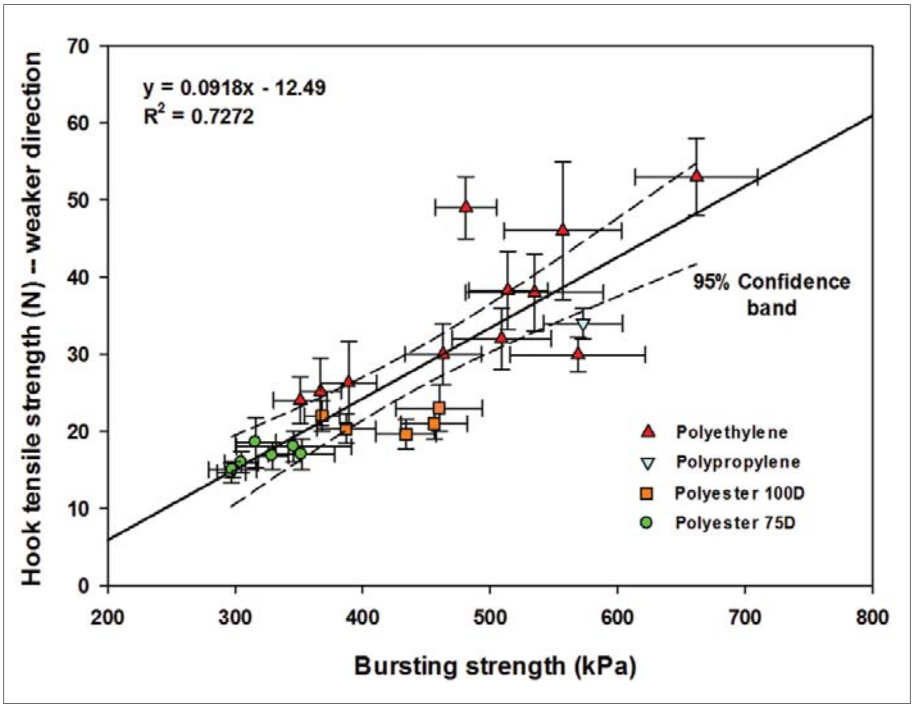


FIGURE A3.44. Comparison of hook tensile strength and bursting strength



TEAR RESISTANCE (BALLISTIC PENDULUM, ELMENDORF TEAR)

As can be seen *Tables A3.7* and *A3.8*, cross-tearing occurred in all the nets tested. With the exception of LifeNet, all the nets had more than 60% cross-tears in either the length or width direction; LifeNet had 33.3% cross-tears in the length direction and 46.6% on the width direction. According to the ISO method, LifeNet is the only LLIN in this study that was suitable for evaluation with this test.

The mean tear resistance rankings of the nets when all tears are considered are shown in *Figure A3.45*; however, the large standard deviations suggest that the difference among LLINs with the lowest and highest tear resistance is minor. This is further illustrated in *Figure A3.46*, which shows that no LLIN clearly outperformed any other.

Table A3.7. Results of ballistic pendulum tear resistance tests across length

LLIN	Panel	Tear resistance (N) across length									
		All tears					Cross-tears excluded				
		n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
DawaPlus 2.0 75 denier		15	9.8	1.1	7.0	11	5	10.4	0.5	10	11
DawaPlus 2.0 100 denier		15	19.8	2.0	14	23	15	19.8	2.0	14	23
Duranet		15	16.8	2.3	14	20	0	–	–	–	–
Interceptor 75 denier		15	9.9	3.8	5.0	15	7	13.4	0.8	13	15
Interceptor 100 denier		15	15.3	1.9	10	19	15	15.3	1.9	10	19
LifeNet		30	18.1	4.7	9.9	25	20	21.8	1.1	15	24
MAGnet		15	15.1	2.8	10	22	2	12.0	2.8	10	14
Miranet		15	16.3	2.6	14	22	0	–	–	–	–
Netprotect		15	11.8	2.2	9.7	18	0	–	–	–	–
Olyset Net		15	13.2	3.8	6.7	19	0	–	–	–	–
Olyset Net (v.2)		15	14.0	3.9	6.6	20	2	7.0	0.5	6.6	7.3
Olyset Plus		15	12.4	1.8	9.3	15	0	–	–	–	–
Panda Net 2.0		15	16.1	3.5	14	22	0	–	–	–	–
PermaNet 2.0 75 denier		15	11.4	1.9	7.8	14	13	11.3	2.0	7.8	14
PermaNet 2.0 100 denier		15	14.8	2.5	10	17	3	16.3	1.2	16	17
PermaNet 3.0 75 denier	Upper side	15	11.3	1.1	9.1	13	5	11.0	0.7	10	12
	Lower side	15	14.2	2.1	11	17	0	–	–	–	–
	Roof	15	8.9	5.6	3.4	17	10	5.2	1.4	3.4	6.5
PermaNet 3.0 100 denier	Side	15	15.2	1.3	13	17	0	–	–	–	–
	Roof	15	11.3	4.9	4.7	18	5	5.6	0.7	4.7	6.3
Royal Sentry		15	16.3	3.2	10	21	5	16.4	4.4	10	21
Yahe 75 denier		15	7.9	1.1	5.6	9.6	0	–	–	–	–
Yorkool 75 denier		15	15.9	2.7	9.0	19	13	16.6	1.7	13	19
Yorkool 100 denier		15	13.3	3.0	10	19	0	–	–	–	–

N = Newton (standard unit of force); SD = standard deviation

Table A3.8. Results of ballistic pendulum tear resistance tests across width

LLIN	Panel	Tear resistance (N) across width									
		All tears					Cross-tears excluded				
		n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
DawaPlus 2.0 75 denier		15	10.8	1.4	8.0	13	0	–	–	–	–
DawaPlus 2.0 100 denier		15	14.5	4.2	9.0	21	0	–	–	–	–
Duranet		15	15.7	4.9	7.6	22	15	15.7	4.9	7.6	22
Interceptor 75 denier		15	11.9	3.1	7.8	17	1	14.0	–	14	14
Interceptor 100 denier		15	14.5	2.7	8.7	19	2	10.9	3.0	9	13
LifeNet		30	14.2	7.6	5.6	24	16	7.9	4.4	5.6	24
MAGnet		15	12.9	3.0	10	21	3	12.1	1.9	10	18
Miranet		15	10.8	3.1	3.7	14	15	10.8	3.7	3.7	14
Netprotect		15	9.4	1.1	7.2	11	15	9.4	1.1	7.2	11
Olyset Net		15	11.6	3.3	6.8	19	15	11.6	3.3	6.8	19
Olyset Net (v.2)		15	11.6	3.7	6.6	16	12	11.0	3.9	6.6	16
Olyset Plus		15	11.9	2.5	9.1	18	15	11.9	2.5	9.1	18
Panda Net 2.0		15	9.8	4.5	3.3	19	15	9.8	4.5	3.3	19
PermaNet 2.0 75 denier		15	10.8	1.8	6.8	13	0	–	–	–	–
PermaNet 2.0 100 denier		15	16.6	2.4	12	20	0	–	–	–	–
PermaNet 3.0 75 denier	Upper side	15	5.4	0.7	4.0	6.5	15	5.4	0.7	4.0	6.5
	Lower side	15	9.1	5.6	3.8	18	10	5.4	1.0	3.8	6.7
	Roof	15	16.5	4.4	11	22	3	14.7	6.4	11	22
PermaNet 3.0 100 denier	Side	15	12.2	4.9	6.5	20	5	7.0	0.6	6.5	7.7
	Roof	15	14.0	5.1	7.5	22	5	8.1	0.6	7.5	8.9
Royal Sentry		15	16.0	3.6	10	23	15	16.0	3.6	10	23
Yahe 75 denier		15	4.8	0.9	3.4	6.5	15	4.8	0.9	3.4	6.5
Yorkool 75 denier		15	14.5	2.1	11	18	5	14.8	3.1	11	18
Yorkool 100 denier		15	13.5	5.9	5.3	20	9	11.8	6.9	5.3	20

N = Newton (standard unit of force); SD = standard deviation

FIGURE A3.45. Ranking of nets according to tear resistance in length direction

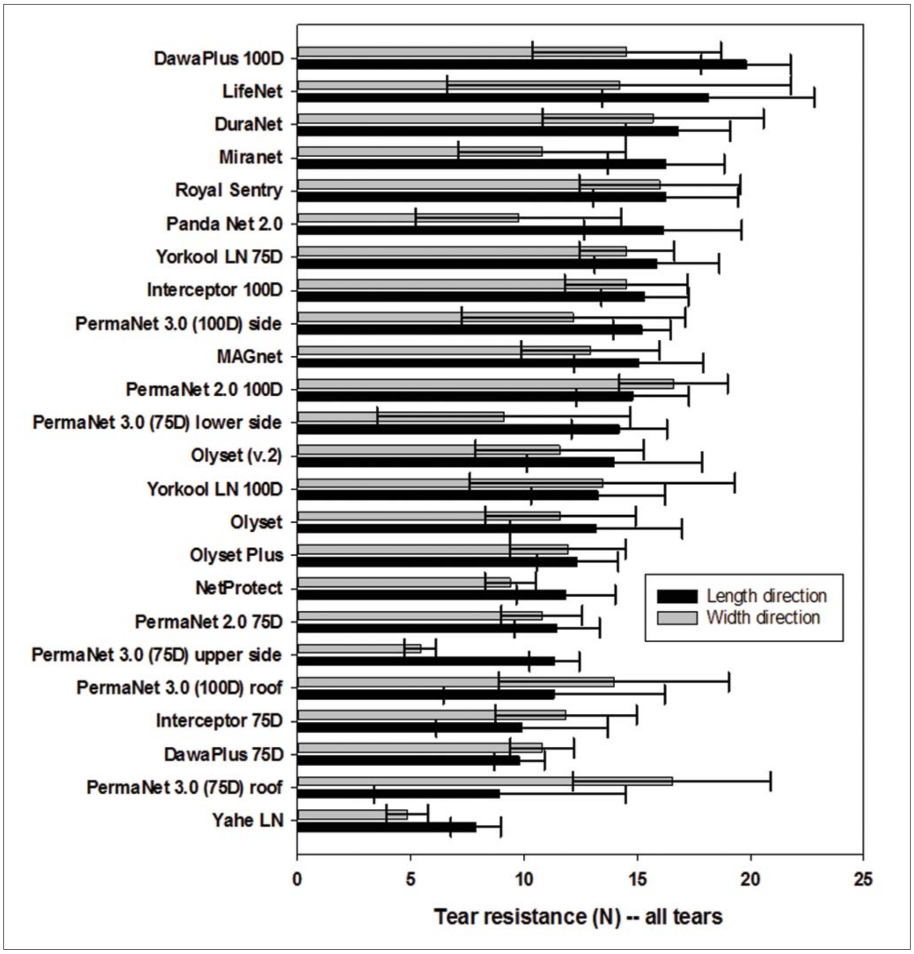
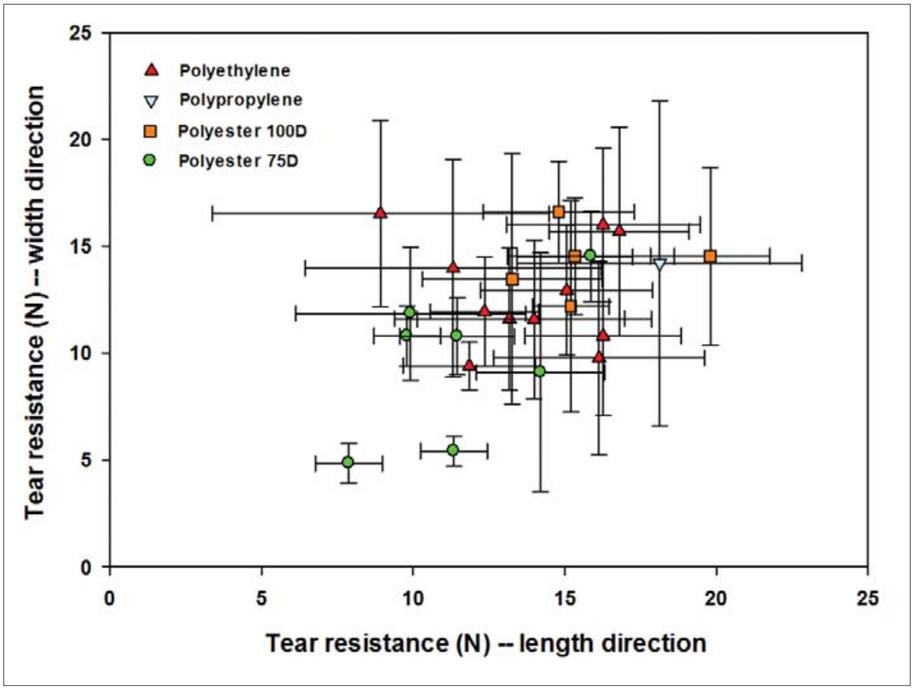


FIGURE A3.46. Tear resistance, length versus width directions (all tears included)



TEAR RESISTANCE (TROUSER, WING AND TONGUE TEAR)

Because excessive cross-tearing was seen in ballistic pendulum testing, trouser, wing and tongue tear tests were performed on samples of DawaPlus 2.0 (100 D) and Royal Sentry nets to determine whether one of these tests would be more suitable. Excessive cross-tearing was also observed in these tests, which were therefore also considered unsuitable according to the ISO guidelines.

FLAMMABILITY (METHOD 16 CFR PART 1610)

In this test, none of the specimens propagated a flame to the test thread. In fact, all the LLINs either did not ignite or self-extinguished. All were classified as normal. The results are shown in *Table A3.9*.

Table A3.9. Results of flammability tests with method 16 CFR 1610

LLIN	Panel	Flammability	
		Test result code	Final classification
DawaPlus 2.0 75 denier		DNI/IBE	1
DawaPlus 2.0 100 denier		IBE	1
Duranet		DNI	1
Interceptor 75 denier		IBE	1
Interceptor 100 denier		IBE	1
LifeNet		DNI	1
MAGnet		DNI	1
Miranet		DNI/IBE	1
Netprotect		DNI	1
Olyset Net		DNI	1
Olyset Net (v.2)		DNI	1
Olyset Plus		DNI	1
Panda Net 2.0		DNI	1
PermaNet 2.0 75 denier		DNI/IBE	1
PermaNet 2.0 100 denier		DNI/IBE	1
PermaNet 3.0 75 denier	Upper side	DNI/IBE	1
	Lower side	DNI/IBE	1
	Roof	DNI/IBE	1
PermaNet 3.0 100 denier	Side	DNI/IBE	1
	Roof	DNI/IBE	1
Royal Sentry		DNI	1
Yahe 75 denier		DNI/IBE	1
Yorkool 75 denier		IBE	1
Yorkool 100 denier		IBE	1

DNI = did not ignite; IBE = ignited but extinguished

FLAMMABILITY (METHOD EN 1102)

As in the CFR flammability test, the flame did not proceed to the test threads in most cases. Some nets continued to burn up to 49 s after the igniting flame was removed, and the flame reached the test threads. These nets dripped flaming melted polymer, which ignited the filter paper placed beneath the sample (*Table A3.10*). When specimens continued to burn, very large holes were created in the netting. The maximum length and width of burn holes in each specimen tested are shown in *Figure A3.47*, which shows that in three instances (in the upper right-hand corner of the graph) the net was entirely consumed. *Table A3.11* shows the numbers and percentages of holes in each net that were wider than 40 mm and 130 mm.

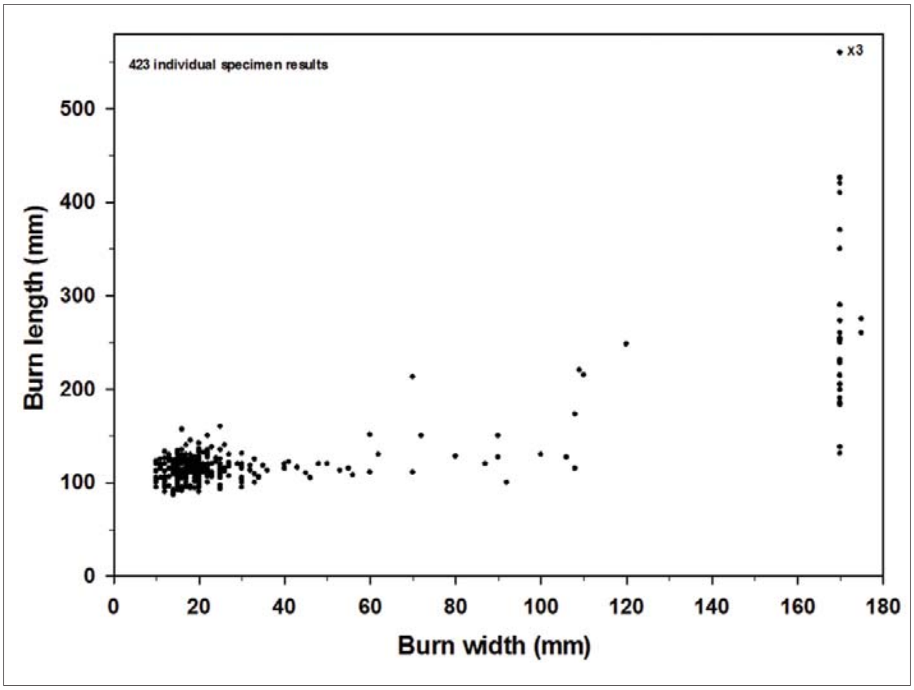
Table A3.10. Burning phenomena observed during vertical flammability test with method EN 1102

LLIN	Panel	Burning phenomena observed (n = 18 per net)			
		Flaming airborne debris (% of specimens)	Post-flame burning time (s)	Ignition of filter paper by drips (% of specimens)	Surface flash (% of specimens)
DawaPlus 2.0 75 denier		0	0	0	0
DawaPlus 2.0 100 denier		0	0–22	56	0
Duranet		0	0	0	0
Interceptor 75 denier		0	0	0	0
Interceptor 100 denier		0	0	0	0
LifeNet		0	0	0	0
MAGnet		0	0	0	0
Miranet		0	0	0	0
Netprotect		0	0	0	0
Olyset Net		0	0	0	0
Olyset Net (v.2)		0	0	0	0
Olyset Plus		0	0	0	0
Panda Net 2.0		0	0	0	0
PermaNet 2.0 75 denier		0	0	0	0
PermaNet 2.0 100 denier		0	0	0	0
PermaNet 3.0 75 denier	Upper side	0	0	0	0
	Lower side	0	0	0	0
	Roof	0	0	0	0
PermaNet 3.0 100 denier	Side	0	0	0	0
	Roof	0	0	0	0
Royal Sentry		0	0	0	0
Yahe 75 denier		0	0	0	0
Yorkool 75 denier		0	0–35	67	0
Yorkool 100 denier		0	0–49	72	0

Table A3.11. Numbers of large burn holes produced during vertical flammability test with method EN 1102

LLIN	Panel	Burn hole width (mm)			
		> 40	%	> 130	%
DawaPlus 2.0 75 denier		0	0	0	0
DawaPlus 2.0 100 denier		10	56	7	39
Duranet		0	0	0	0
Interceptor 75 denier		0	0	0	0
Interceptor 100 denier		0	0	0	0
LifeNet		0	0	0	0
MAGnet		0	0	0	0
Miranet		0	0	0	0
Netprotect		0	0	0	0
Olyset Net		1	0.6	0	0
Olyset Net (v.2)		2	11	0	0
Olyset Plus		0	0	0	0
Panda Net 2.0		1	0.6	0	0
PermaNet 2.0 75 denier		3	17	0	0
PermaNet 2.0 100 denier		0	0	0	0
PermaNet 3.0 75 denier	Upper side	4	22	0	0
	Lower side	0	0	0	0
	Roof	1	0.6	0	0
PermaNet 3.0 100 denier	Side	2	11	0	0
	Roof	0	0	0	0
Royal Sentry		0	0	0	0
Yahe 75 denier		4	22	0	0
Yorkool 75 denier		14	78	7	39
Yorkool 100 denier		14	78	13	72

FIGURE A3.47. Maximum burn hole length and width for all specimens tested in method EN 1102



DISCUSSION

The objectives of testing the strength of LLINs are to identify laboratory tests for defining the quality of nets and to identify nets with the least tendency to be damaged and develop holes in everyday use. Furthermore, if a net does develop holes, they should be small and remain small so that the barrier function of the net is not excessively compromised. Knitted textiles, such as LLINs, are generally considered ill suited for many standard tests of textile strength because of their unpredictable rupturing behaviour and poorly reproducible results. This study confirmed that LLINs perform poorly in grab tensile, ballistic tear, trouser tear, wing tear and tongue tear tests. According to the ISO guidelines, these tests are therefore not suitable.

The only unmodified ISO strength test in which LLINs performed well was that for bursting strength. Currently, WHO requires a bursting strength test for LLINs, in which an LLIN must have a bursting strength > 250 kPa. As holes are unlikely to form by bursting in everyday use, two additional tests of more realistic failure mechanisms, the hook tensile test and the wounded bursting strength test, were evaluated.

The hook tensile test is a modification of the grab tensile test, in which clamps with hooks are used to hold the specimen in place. The objective is to simulate hole formation by snagging. The test was conducted in both the length and width directions of the fabric, the latter showing lower strength in most cases. For oriented fabrics such as these, the strength in the weakest direction is likely to be the best indicator of the tendency for holes to form by snagging, and a strong correlation was found ($r^2 = 0.7272$) when the results were compared with those for bursting strength. This suggests that the standard bursting strength method is suitable for measuring the susceptibility of nets to develop holes by snagging and that standardization of the hook tensile test may be unnecessary.

The wounded bursting strength test is a modification of the usual test, in which a specimen receives a small cut before testing. LLINs almost always develop small holes by snags, burns and other mechanisms, which could increase the susceptibility of the net to subsequent damage. In this test, a minimal cut was made on one side of a mesh hole at the centre of the specimen before testing. In all cases, the bursting strength decreased significantly (28–81%) after wounding. Polyethylene monofilament nets performed least well, losing 70–81% of their bursting strength, while other nets lost only 28–44%. Wounded bursting strength shows promise as a measure of a net's tendency to allow holes to enlarge. Therefore, a low wounded bursting strength should correlate to a high proportion of large holes in nets recovered from the field.

Flammability was tested with two methods. The first, 16 CFR 1610, is the test currently specified by WHO, in which a sample is tested at a 45° angle. The second, EN 1102, is designed for vertically oriented fabrics, such as curtains. All LLINs passed the 16 CFR 1610 test; however, the EN 1102 test revealed differences in the LLINs tested. Exposure to a flame usually produced a hole 5–36 mm wide and 87–150 mm long, but some specimens continued to burn, thus enlarging the holes. These results were communicated to the relevant LLIN manufacturers during the WHO consultation. Furthermore, three LNs generated flaming polymer drips 56%, 72%, and 67% of the time, respectively, which could cause serious personal injury and start secondary fires.

CONCLUSIONS

- According to the ISO guidelines, the rupture behaviour of nets tested in this study make the grab tensile, ballistic tear, trouser tear, wing tear and tongue tear test methods unsuitable for testing them.
- The results of hook tensile tests generally correlated with bursting strength ($r^2 = 0.7272$), suggesting that the standard bursting strength test is suitable for evaluating resistance to hole development by snagging. Further comparisons should be made to determine whether the standard bursting strength test can fully replace the hook tensile test.
- The wounded bursting strength test revealed striking differences in the bursting strengths of nets after minimal wounding. This test shows promise as a measure of the tendency of small holes in a net to enlarge, possibly allowing prediction of the proportion of large holes in nets.
- For evaluating flammability, EN 1102 is superior to 16 CFR 1610, as specimens can be tested in a vertical orientation, as in normal use. Furthermore, testing with EN 1102 showed that some nets continue to combust after removal of the flame, resulting in extreme hole enlargement and, in some cases, dripping of flaming polymer melt. In a household, flaming melt could cause serious personal injury and ignite other combustible items, allowing the fire to spread further.

RECOMMENDATIONS

The results of the study suggest that WHO and the research community should conduct further work, as outlined below.

- Support coordinated multicentre field trials to compare the fabric strength of multiple LLIN products (brands) in the same countries.
- Seek correlations between the results of field trials and of laboratory textile tests in order to identify measures to predict the physical durability of nets in operational settings.
- Include the fabric weight of netting as part of WHO specifications for LLINs.
- Develop specifications for the flammability of WHOPES-recommended nets based on the EN 1102 vertical test, and include this test in WHO specifications for LLINs.
- Continue to seek novel laboratory tests for the durability of LLINs.
- Continue to test new and improved LLINs that are submitted to WHOPES.

ANNEX 4. INTRODUCTION TO RESISTANCE-TO-DAMAGE VALUES

RATIONALE

The long-term durability of LLINs in terms of resistance to hole formation depends on the inherent "strength" or resistance of the fabric to damage and the intensity of use of the net in the field. Studies by the R4D consortium showed that most holes in LLINs in the field in different countries and settings are due to mechanical damage, comprising snagging, tearing, abrasive wear and hole propagation after an initial yarn break. The introduction of new textile testing methods that directly reflect the actual mechanisms of damage in the field can lead to more appropriate laboratory measures of "strength" or resistance to damage.

NEW TEXTILE TESTING SUITE

By comparing actual damage seen in the field with what can be measured in the laboratory, four textile test methods were identified, all of which are designed to reflect real conditions.

BURSTING STRENGTH

Bursting strength is measured according to ISO 13938-2:1999. In addition to providing a measure of overall fabric strength in knitted fabrics, bursting strength has been found to correlate with the number of tears observed in field nets. It is therefore considered a useful assessment of tear resistance.

SNAG STRENGTH

This test allows quantification of the force necessary to create a hole in fabric as a result of yarn breakage when plucked from the surface. It simulates a fabric being caught and pulled away from a rigid protuberance, as often happens in the field. The method is adapted from EN 15598:2008. A hook is used to catch a mesh section of the net perpendicular to the plane and extend it to break. The force required to break the yarn is recorded. The test is repeated in the course and wale directions of the fabric, and the mean value is recorded.

ABRASION RESISTANCE

An accelerated Martindale method adapted from ISO 12947:1998 is used. Samples are abraded against a specific grade of fine sandpaper; the failure point of each specimen is reached when a yarn breaks, creating a hole ≥ 0.5 cm. The number of rubs at which this occurs is recorded.

HOLE PROPAGATION

Holes in LLINs can enlarge over time. In this test, a hole is made in a net under controlled conditions and is gradually enlarged under controlled multi-axial loading. The hole size is measured after the test. This method is adapted from the wounded burst test BS 3424-38:1998. In addition to the hole size, any secondary damage in the form of laddering, unravelling or tearing of the knitted fabric is recorded, as such secondary damage can lead to very large holes. The presence of secondary damage lowers the resistance of the net to damage.

VALUE OF RESISTANCE TO DAMAGE

A "resistance to damage" (RD) score is a composite of the results obtained from each of the four textile tests: bursting strength, snagging strength, abrasion resistance and hole propagation. The results of each test are compared with "aspirational values", which represent target values based on the real forces that an LLIN is likely to encounter in use. The nearer the test value is to the aspirational target, the better the overall RD score.

Figure A4.1 shows the steps required to calculate the RD value for each LLIN. First, the mean values are obtained from each of the four textile testing methods. Secondly, each value is compared with its corresponding aspirational value, and the difference between the two is expressed as a percentage. For example, if the aspirational snag strength is 200 N and the net achieves 100 N in the snag test, the result is 50% of the aspirational target. Finally, this proportional score is divided by 4 and summed with the other individual values, so that the final RD score can be expressed as a single percentage (*Figure A4.2*).

Figure 4.1. Method for calculating RD score

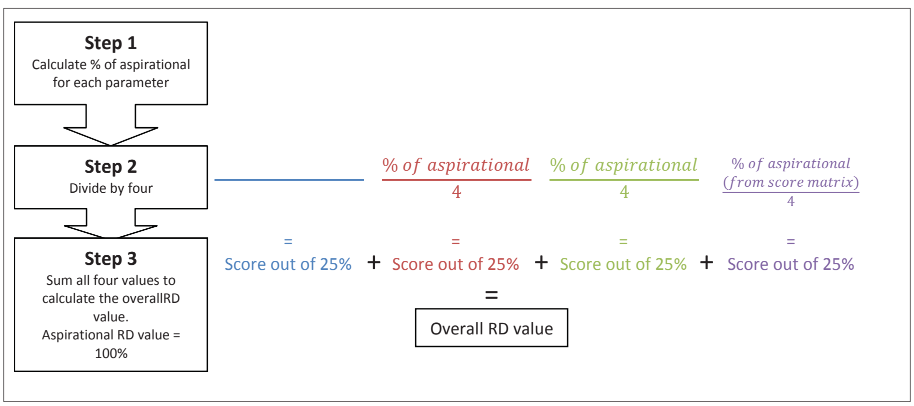
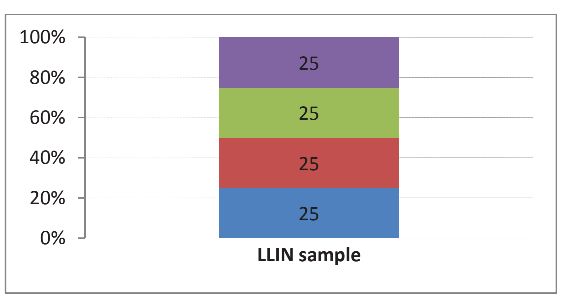


Figure 4.2. Aspirational results for an LLIN with an RD score of 100%



Blue, tear resistance; red, snag strength; green, abrasion resistance; purple, hole propagation