PENETRATION AND ADHERENCE OF *CARUKIA BARNESI* TENTACLES TO VARIOUS CLOTHING FABRICS

Consultants

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1.1 List of Contents

1.2 Executive Summary

Surf Life Saving management requested that their lycra stinger Personal Protective Equipment be tested and evaluated against other products and potential products on the market, with respect to Irukandji safety. Of particular concern to SLS management were: penetration potential of tentacles, adherence of medusa body parts to fabric, potential for crushing of medusa body parts into fabric, and durability of product, i.e., integrity of barrier.

Lycra PPE has been widely used since the 1980's (Williamson et al., 1996; Harrison et al., 2004), but has not been formally tested as a barrier against Irukandji (*Carukia barnesi*) tentacles. A more recent, widely-used product marketed as "The Stinger Suit" (ROBIS Pty. Limited) is reputed to protect from Irukandji stings (Seymour, unpublished), but no test results are available for evaluation.

Six products were tested: the SLS Lycra, the ROBIS product, three different styles of pantyhose, and a sport product designed to keep the wearer cooler. Neoprene is also in use (James Cook University) for stinger safety, but was not tested.

Penetration: All products tested except the ROBIS product are too fine-meshed to allow tentacles to penetrate the fabric under normal circumstances; tentacles draped into and plunged into the ROBIS product, providing a potential hazard for increased envenomation by trapping the tentacles against the wearer's skin.

Adherence: The two "non-silky" pantyhose products clearly promoted tentacle adherence; tentacle bands were caught horizontally in the texture of the SLS garment; the bell readily adhered to the ROBIS product. Prolonged adherence to garments could enhance probability of envenomation by two methods. First, prolonged contact with garments could increase probability of tentacle penetration or crushing of medusa body parts, simply by still being in contact with the fabric. Second, attachment of tentacles could result in detachment from the medusa, and subsequent envenomation during disrobing from unnoticed tentacles.

Crushing: All products tested are believed to be penetrable to medusa body parts crushed into the fabric, such as might occur during activity inside the elbow, under the armpit, or between the legs, resulting in envenomation. The only product currently known to resist tentacle crushing complications is neoprene, which provides an impenetrable barrier.

Durability: The three pantyhose products are believed to be too delicate for normal patrol and recreational activity, resulting in runs, seam-splits, or other lapses in barrier integrity; the ROBIS product might also be considered too delicate for repeated wear during normal activity.

All products tested are believed to be cooler than neoprene, and thus more likely to be wearable for prolonged periods during patrol and recreational activities.

These tests were recorded on DVD Video and are available for examination.

1.3 Description of the contract

Objectives

1. Evaluate different potential Personal Protective Equipment for penetrability and adhesion of *C. barnesi* tentacles;
2. Of particular interest are: mesh size, weave pattern, fabric ingredients, and durability of fabric under sporting conditions;
3. Rate different fabric types relative to one another on the following criteria: tentacle penetration, tentacle adhesion, and durability
4. Discuss findings with Surf Life Saving management;
5. Write a report on the findings and recommendations based on the outcomes. Options would also be given for future research and steps to minimize the risk of jellyfish envenomation.

1.4 Background

1.4.1 The problem

Numerous serious Irukandji envenomations occur each year in North Queensland waters, due to *Carukia barnesi* and other species of jellyfishes. Personal Protective Equipment (PPE) is recommended, but no standards currently exist. This contract was initiated by Surf Life Saving (SLS) management, in order to evaluate the effectiveness of SLS-issue PPE and other readily-available products.

Figure 1. *Carukia barnesi*, adult, approximately 11mm bell height, photographed under dissecting microscope.

1.4.2 SLS Personal Protective Equipment

Surf Life Saving currently requires all paid and volunteer persons working in jellyfish-infested waters to wear PPE, and further recommends that the public wear PPE to ensure a safe and healthy marine experience. Current SLS protocols require the wearing of two lycra body suits, in order to reduce the risk of envenomation.

Figure 2 *Carukia barnesi* tentacle under dissecting microscope; note bands of stinging cells. Uncontracted tentacle diameter is approximately 250µm (1/4 mm). When completely relaxed, major bands are approximately 2cm apart.

1.4.3 Other standards

James Cook University requires cubozoan researchers to wear a minimum of 0.5mm thickness neoprene when working in cubozoan-infested waters, but has no enforced standards for non-cubozoan researchers.

1.4.4 SLS concerns

Safety in all its forms is of the utmost importance to SLS. This includes not only stinger protection, but also other irritants, heat-stress, and U/V exposure, to name just a few.

1.4.5 Potential lycra problems

Sinclair (2003) found that lycra body suits may retain heat, causing potential heat-stress problems for life guards and life savers on patrol. Furthermore, several stings have occurred through lycra when tentacles and other medusa body parts are crushed through fabric, allowing stinging cells to come into contact with human skin. Similarly, medically insignificant box jelly stings have occurred through lycra suits, presumably from free stinging cells in the water; the effect of free Irukandji stinging cells is unknown.

1.4.6 Other available products

For many years, nylon pantyhose were recommended for stinger protection. These were generally phased out with the advent of lycra body suits (P. Fenner, pers. comm., 2000), which provide a thicker layer of protection, more durability, and better U/V protection than pantyhose.

ROBIS Pty. Limited makes and distributes a lightweight-mesh product known as “The Stinger Suit,” which has been widely adopted due to its lower price, cooler mesh, and endorsement by James Cook University. ROBIS Pty. Limited requested that Surf Life Saving evaluate their product.

Many sport-wear companies distribute products which “wick” away moisture, thus keeping the wearer cooler than with standard clothing products. These have not traditionally been used for stinger protection.

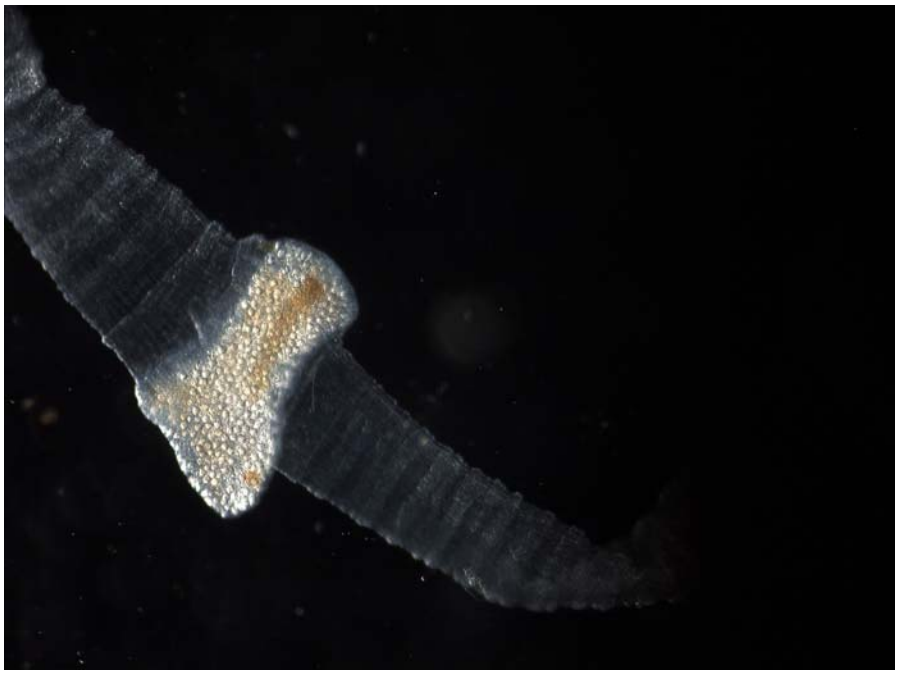

Figure 3. – Close up of a tentacle section of *Carukia barnesi* under microscope; the bright-coloured dots on the band are the stinging cells themselves (approx. 25µm long, or 25/1000ths of a mm).

1.4.7 Objectives of the report

- Review the problem
- Compare options for clothing products for stinger protection that decrease risk to the public
- Advise on comparative strengths and weaknesses of different products
- Indicate areas of research that would allow better stinger protection evaluation in the future.

1.5 Materials and methods of testing

1.5.1 Testing method

Fabrics were tested individually, by wrapping around the “lid” of a standard (90mm) glass petri dish, then securing the fabric to one side so that the testing surface was snug but not stretched. The product was then placed into a large (150mm) glass crystallizing bowl, the bowl was filled with seawater from the *Carukia barnesi* breeding lab, then a mature (or nearly so) specimen of *C. barnesi* with intact tentacles was gently placed onto the testing surface. The “bottom” half of the petri dish was placed over the testing surface to keep the animal from swimming away. The whole testing unit was then carefully submerged in order to free any bubbles caught in the system.

Each test lasted a minimum of 10 minutes, during which time the tentacles interacting with the mesh were filmed through the eye piece of a Leica dissecting scope with a Sony Handycam DVD -201. Additionally, still images were captured with both the Sony Handycam and a Nikon CoolPix 995 through the eye piece of the same scope.

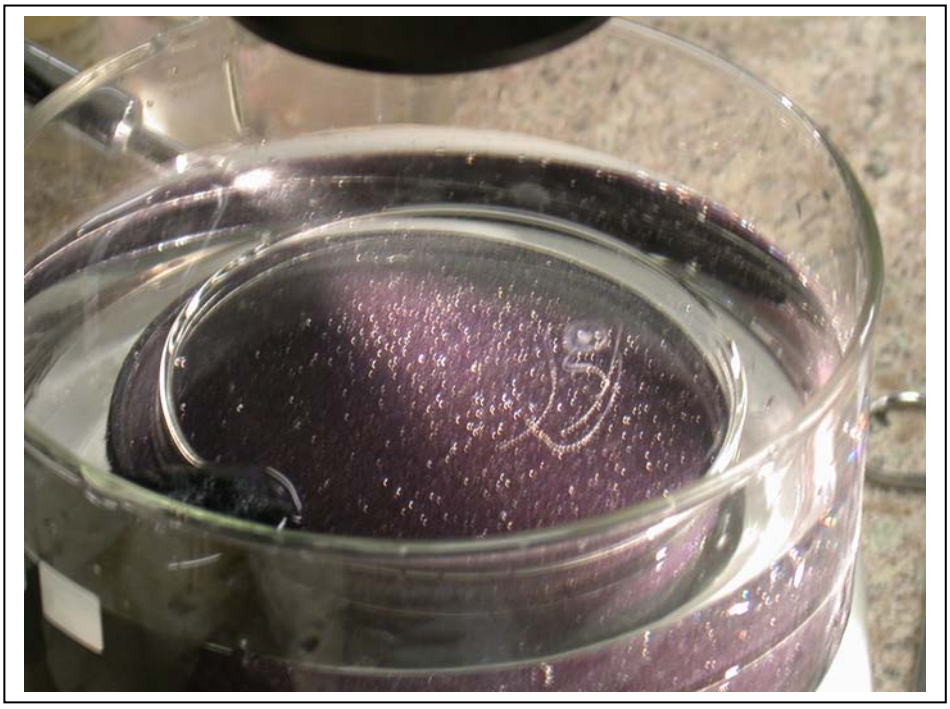

Figure 4. Testing chamber. Note fabric stretched across petri dish, with smaller petri dish cap to keep medusa from swimming off testing surface, all placed inside a larger glass bowl.

1.5.2 SLS-issue Lycra body suit

The sleeve from an old, repeatedly-worn SLS-issue Lycra suit was tested. A red section was tested preferentially over yellow, to provide contrast for filming. Whether the “worn-ness” factor of the suit had any effect was not tested, as most suits would be worn repeatedly in normal SLS operations.

1.5.3 ROBIS Pty. Limited “Stinger Suit”

A new and previously unused glove was tested straight from the package. A black suit was used, to provide contrast for filming. Whether the “new” factor of the glove had any effect was not tested, but is believed to possibly present an unnatural situation, since most suits would be likely to be worn repeatedly.

1.5.4 Fine, sheer pantyhose

A new and previously unused anklet-style garment was tested, marketed as Kolotex Kicks Fresh Anklets. The darkest colour found was used, to provide contrast for filming. Whether the “new” factor of the garment had any effect was not tested, as most pantyhose products would be unlikely to be worn repeatedly.

1.5.5 Thicker-threaded pantyhose

A new and previously unused anklet-style garment was tested, marketed as Kayser Razza-matazz Opaque Anklet. The darkest colour found was used, to provide contrast for filming. Whether the “new” factor of the garment had any effect was not tested, as most pantyhose products would be unlikely to be worn repeatedly.

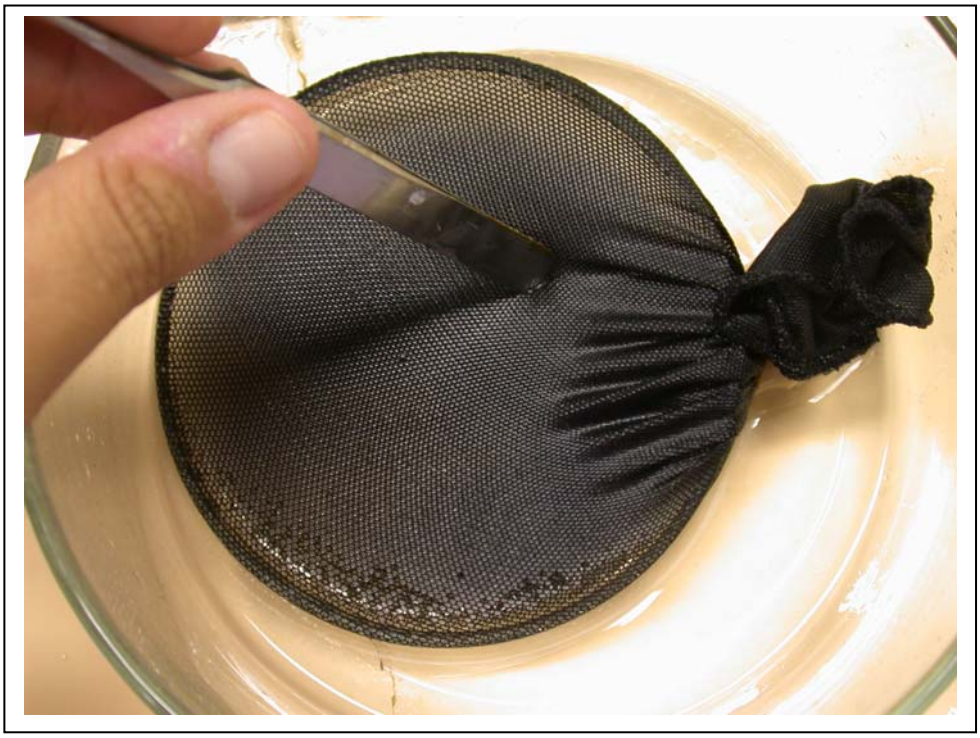

Figure 5. Testing chamber, uncovered. Forceps used to illustrated tautness of fabric, pulled snug, but not stretched to expansion. Garment in this figure is the ROBIS product, but all products were tested at a similar snugness. It should be noted that some body types and activities would stretch fabrics more than others.

1.5.6 Silky pantyhose

A new and previously unused knee-hi-style garment was tested, marketed as Kmart NOW Legwear Sheer Anklets. The darkest colour found was used, to provide contrast for filming. Whether the “new” factor of the garment had any effect was not tested, as most pantyhose products would be unlikely to be worn repeatedly.

1.5.7 Nike “Dri-Fit” sport shirt

A new and previously unworn sport shirt was tested. This product had two types of mesh, one with a closed weave and the other with regularly-spaced small holes. Whether the “new” factor of the garment had any effect was not tested, but is believed to possibly present an unnatural situation, since most PPE of this type would be likely to be worn repeatedly.

Product results

1.5.8 General results

All products tested are believed to be permeable to crushing of tentacles or other medusa body parts, resulting in envenomation. The only product known to the consultants at this time that would be completely impermeable would be neoprene, which was not tested.

All products tested have mesh that is too fine to allow intact penetration of tentacles, except the ROBIS product.

About half the products are believed to be durable enough for normal activity, i.e., the protective integrity of the product remaining intact; all three pantyhose products are believed to be too delicate for normal active wear.

1.5.9 SLS-issue Lycra body suit

Carukia barnesi tentacles were not able to penetrate the Lycra mesh. There was a notable "stickiness" of the tentacles to the product, believed to be the result of attempts at horizontal movement by the jellyfish over the ridged surface of the product, i.e., the tentacular bands were easily caught in the "valleys" and could not get over the "mountains" of the fabric. The effect that this could have in a natural situation is unknown, but must be regarded as a possible hazard.

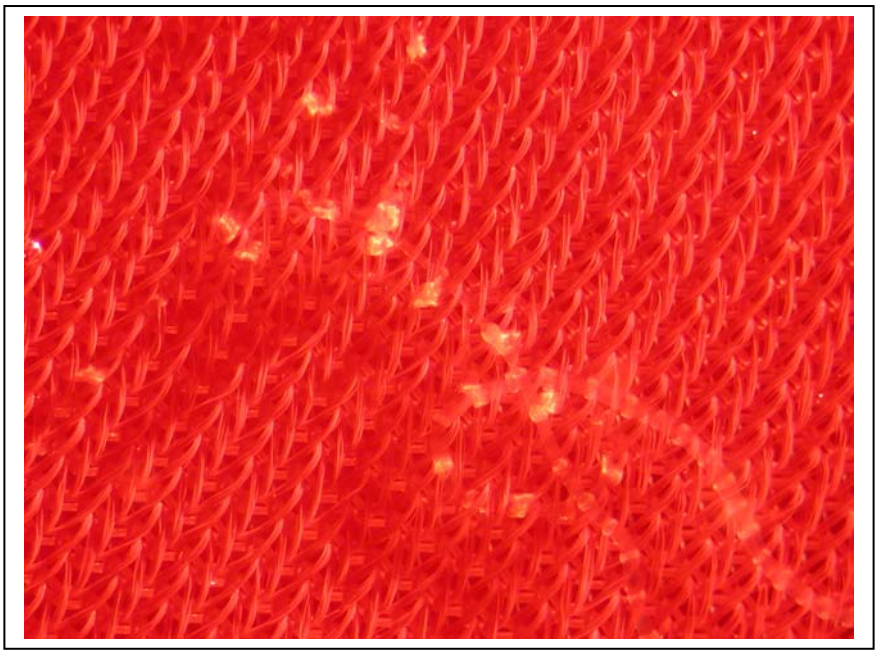

Figure 6. *Carukia barnesi* tentacles and the SLS-issue Lycra PPE. Note tentacles stretched due to catching in the mesh (upper left), compared with unstretched tentacles (lower right), evidenced by distance between major bands.

1.5.10 ROBIS Pty. Limited "Stinger Suit"

Carukia barnesi tentacles easily and readily penetrated the ROBIS mesh, observed both as draping of the tentacle into the mesh as well as plunging of the tentacle tips through the fabric. It was also observed that the tentacles actively probed around while inside the mesh. Furthermore, periodically the animal would rapidly contract the tentacles, pulling them out of the mesh, but retraction of the tentacles was inevitably hampered by brief catching on the mesh.

Carukia barnesi bells repeatedly adhered to the mesh, providing an opportunity for the animal to become stuck to the garment long enough for tentacles to penetrate the mesh, or medusa body parts to be crushed through the fabric, in a real-life situation.

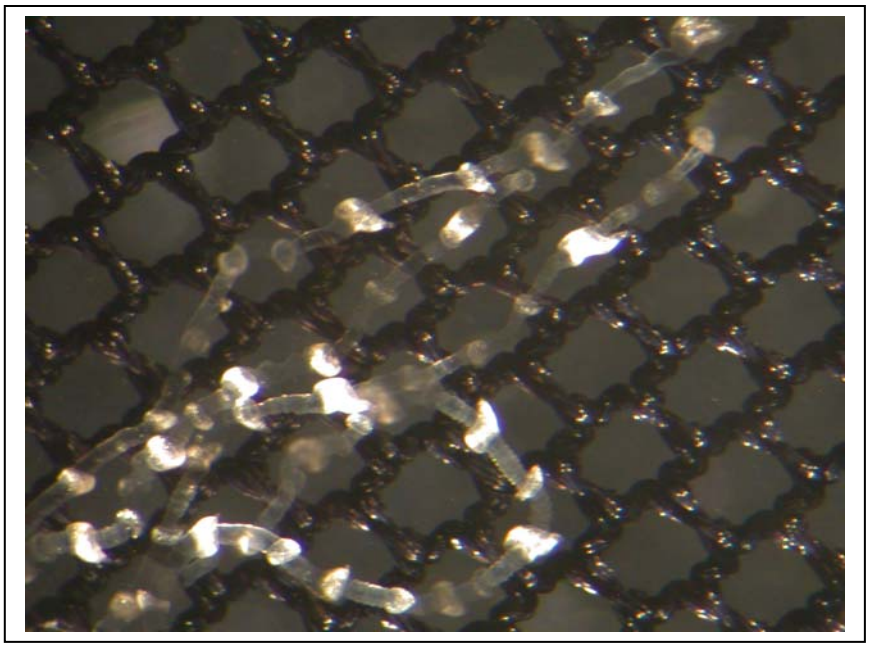

Figure 7. *Carukia barnesi* tentacles and the ROBIS Pty. Limited "Stinger Suit." Unstretched mesh diameter is about 1mm. Note tentacles draping into mesh (lower left and centre), and tentacle tip plunging into mesh (upper right).

1.5.11 Fine, sheer pantyhose

Carukia barnesi tentacles were not able to penetrate the fine, sheer pantyhose mesh. However, the tentacles became so complexly adhered to the mesh that they had to be removed with dissecting tools and in the end, a tentacle was lost to the process. We believe that the "roughness" of the fabric surface is prone to tentacle capture.

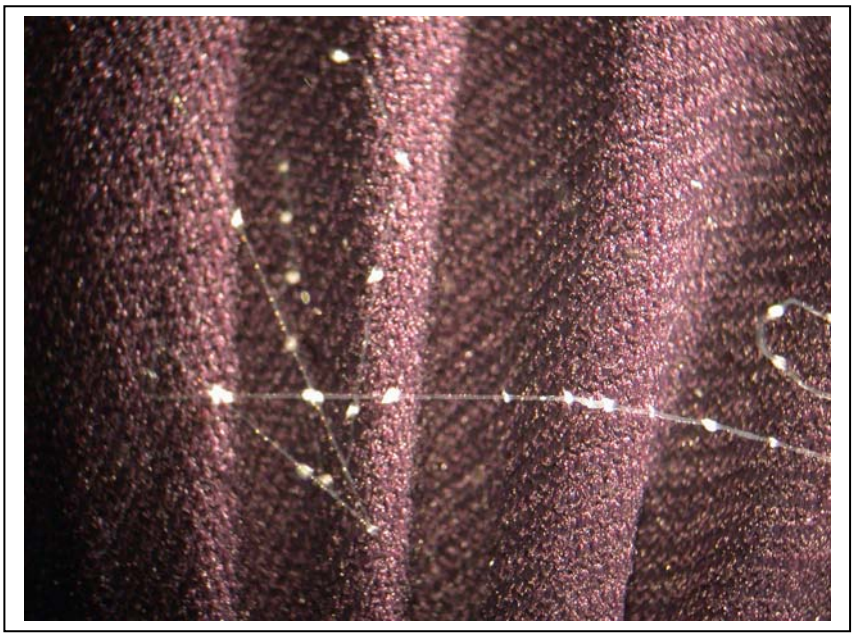

Figure 8. *Carukia barnesi* tentacles and fine, sheer pantyhose. Note many places where tentacles are caught on mesh.

1.5.12 Thicker-threaded pantyhose

Carukia barnesi tentacles were not able to penetrate the thicker-threaded pantyhose mesh. However, like the fine, sheer pantyhose, but to a somewhat lesser extent, the tentacles became adhered to the mesh. We believe that the “roughness” of the fabric surface is prone to tentacle capture.

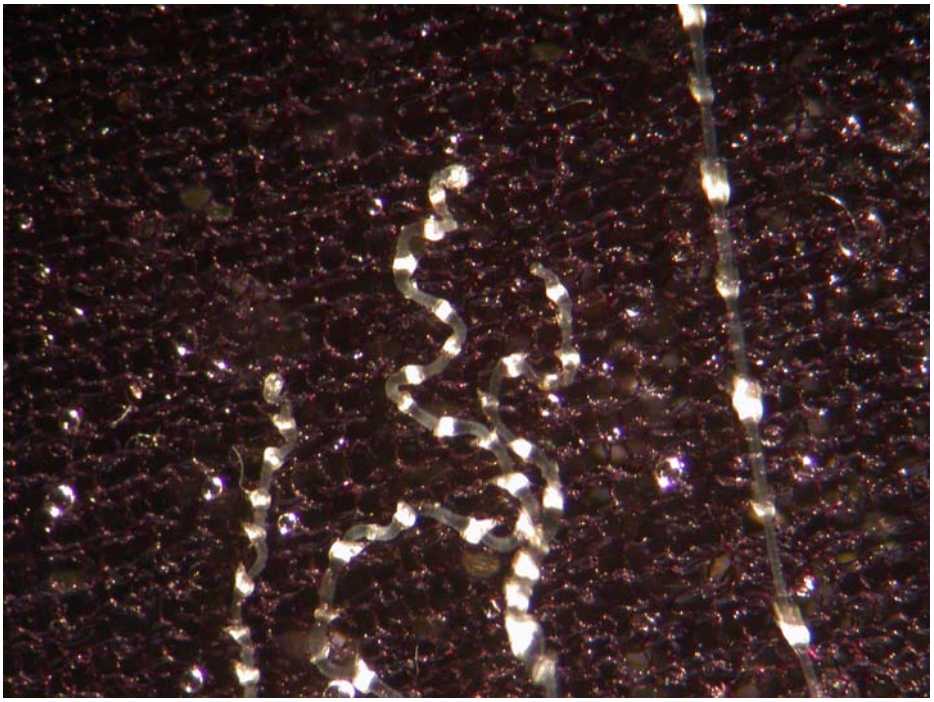

Figure 9. *Carukia barnesi* tentacles and the thicker-threaded pantyhose. Note stretched tentacle which has caught on the mesh (right).

1.5.13 Silky pantyhose

Carukia barnesi tentacles were not able to penetrate the silky pantyhose mesh, which is semi-open on the outer surface with finer cross-fibers below. During the testing, the tentacles were observed to be caught (evidenced by the struggling medusa against tightened tentacles); however, after testing this phenomenon was observed to be due to two factors, one of which may be risky and one which is not. One of the tentacles was terribly entwined in a loose thread from a “run” in the pantyhose caused by the jellyfish-holding container during transfer of the medusa to the testing chamber. Loose threads from such a run could thus pose a hazard during normal use. Another tentacle was later observed to have been caught by the edge of the upper petri dish where it layed against the mesh at the outer edge of the testing chamber; this situation would be unlikely to pose a normal hazard. Repeated attempts at subsequently sticking the tentacles and bell to the mesh were unsuccessful.

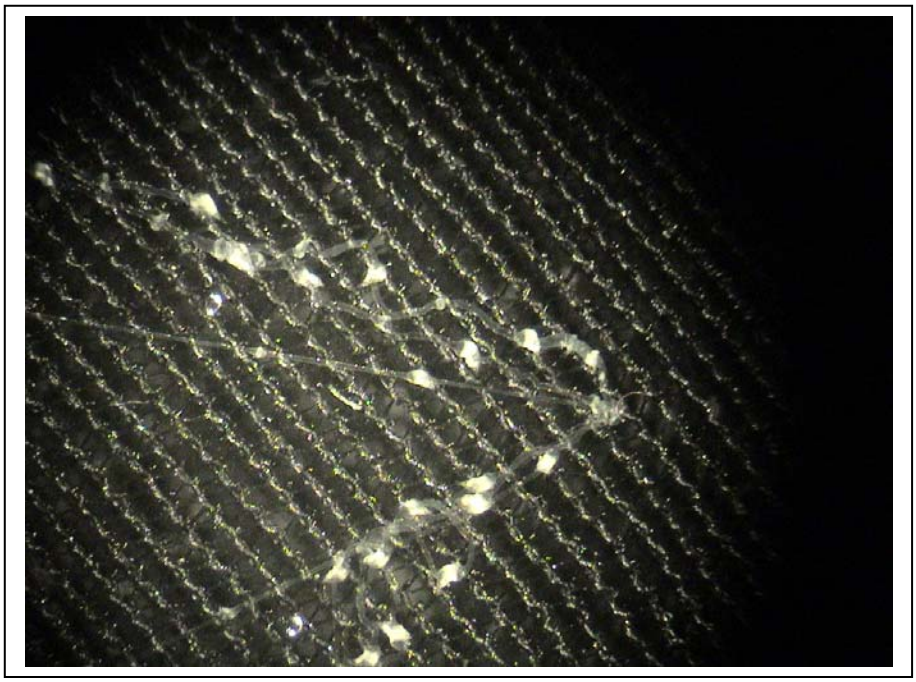

Figure 10. *Carukia barnesi* tentacles and the silky pantyhose. Note the tentacles entangled in a loose thread from a run (centre and bottom), and a stretched tentacle caught in the edge of the testing chamber (beyond photo, to left). Once these two issues were resolved, the tentacles and bell could not be made to stick to the fabric.

1.5.14 Nike "Dri-Fit" sport shirt

Carukia barnesi tentacles were not able to penetrate either of the styles of the Dri-Fit mesh during testing; however, we believe that under some circumstances the chance for penetration through the "holed" mesh would be possible. Neither the bell nor tentacles were observed to stick the product.

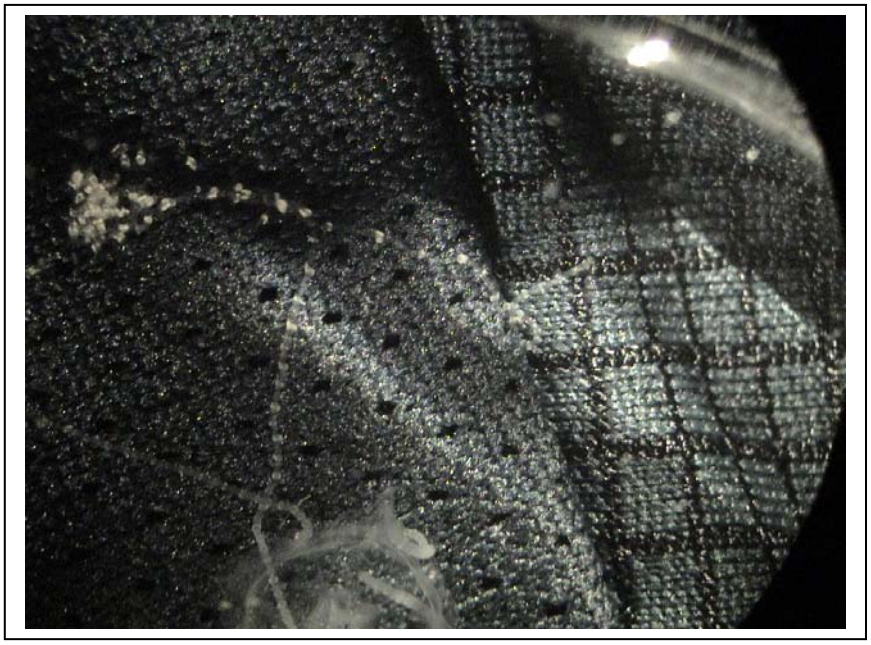

Figure 11. *Carukia barnesi* tentacles and the Nike Dri-Fit sport shirt. Note two types of weave in the test area, a weave with regularly-spaced small holes to the left, and a closed weave to the right.

1.6 Methods for reducing envenomation and recommendations

The categories of envenomation reduction that we have identified include:

1. impenetrability of fabric weave;
2. resistance of tentacle adherence to fabric;
3. possibility of crushing tentacles through fabric;
4. durability of fabric, i.e., integrity of barrier
5. heat-reducing properties, such that the PPE will be continuously wearable during normal patrol and recreational activity

Each product is ranked for each of the above categories on a scale of 1-5 as follows:

1 = poor
2 = substandard
3 = satisfactory
4 = above standard
5 = excellent

The different items tested are summarized below, along with their advantages and disadvantages. An overall assessment is based on the general probability of reducing envenomation, given penetration, adherence, crushing, and durability. Heat-reducing properties are not taken into account in the overall assessment, but are noted as applicable. Items are ranked in the table with the highest overall protection at the top of the table, and the lowest overall protection at the bottom of the table. We strongly support the use of items listed in the first 4 rows.

Item	Advantage	Disadvantage	Overall assessment
0.5mm Neoprene wetsuit	1) Impenetrable (5) 2) Tentacles cannot crush through fabric (5) 3) Quite durable (5)	1) High risk of overheating (1) 2) Tentacles may adhere to surface (2) 3) Expensive ($150-200)	Advisable for high-risk conditions, but too hot for normal conditions
SLS-issue lycra body suit	1) Tentacles cannot penetrate mesh (5) 2) Moderately durable (4) 3) Relatively inexpensive (<$100)	4) Poor heat dispersion (2) 5) Tentacles may adhere to surface (2) 6) Tentacles can be crushed into mesh (2)	Recommended for normal level of stinger protection
Nike Dri-Fit sport shirt	1) Tentacles cannot penetrate mesh (5) 2) Tentacles do not catch on mesh (5) 3) Cool (4) 4) Quite durable (4)	1) Tentacles may be crushed through fabric (2) 2) Expensive ($60 shirt) 3) Not available as one-piece suit	Recommended for situations where one-piece lycra is not practical

Pantyhose: Kmart NOW Legwear Sheer Anklets (silky)	1) Tentacles cannot penetrate mesh (5) 2) Tentacles do not catch on mesh (5) 3) Inexpensive (<$10) 4) Cool (4)	1) Tentacles may be crushed through fabric (2) 2) Not durable (1) 3) Not available as 1-piece body suit	Recommended for low-activity situations; reduces tentacle adherence
Pantyhose: Kayser Razza-matazz Opaque Anklets (thick, black thread, non-silky)	1) Tentacles cannot penetrate mesh (5) 2) Inexpensive (<$10) 3) Cool (4)	1) Tentacles somewhat prone to catching on fabric (2) 2) Tentacles may be crushed through fabric (2) 3) Not durable (1)	Low to moderate level of protection; better than cheaper pantyhose
Pantyhose: Kolotex Kicks Fresh Anklets (thin, sheer thread, non-silky)	1) Tentacles cannot penetrate mesh (5) 2) Inexpensive (<$10) 3) Cool (4)	1) Tentacles prone to catching on fabric (1) 2) Tentacles may be crushed through fabric (2) 3) Not durable (1)	Better than nothing, but high risk of tentacle adherence
ROBIS Pty. Limited "Stinger Suit"	1) Lightweight and cool (5) 2) Inexpensive ($25-40)	1) Tentacles drape into open mesh and plunge through it (1) 2) Body and tentacles adhere to surface (1) 3) Not particularly durable (2)	Likely to prevent lethal *Chironex* envenomation, but may promote *Carukia* sting by trapping tentacles; not recommended for most activities

It should be noted that there is a trade-off between penetrability of fabric and heat-retention, with the highest level of protection (neoprene) also highly likely to cause heat-related health problems, but the highest level of heat-related protection ("Stinger Suit") also likely to allow penetration of *Carukia* tentacles. It is therefore our recommendation to consider the 5 factors enumerated above in light of particular desired activities when choosing PPE.

1.7 Options for future research

Neoprene was not tested in this evaluation, but should be included in future tests. While there would be no possibility that *Carukia barnesi* tentacles could penetrate neoprene, no information currently exists as to whether it resists tentacle adherence. Adherent tentacles could come into contact with skin during disrobing, and all precautions must be taken to neutralize any adherent nematocysts prior to disrobing.

Other types of sport clothing might also be tested, such as runner's and biker's tights. One product in particular that we searched for but were not able to find was Low Alpine, a light-weight lycra-type clothing product with wicking properties for heat dispersion.

1.8 Consultation with Surf Life Saving management

Peter Dawes (Operations Manager)
Peter Roulston (Regional Manager)
Grant Small (Lifeguard Supervisor, Cairns region)
Liam Drake (Lifeguard Supervisor, Townsville region)
Paul Barker (Lifeguard Supervisor, Mackay region)
Bill Horsford (Development Officer, Cairns region)
Elliott Bates (Development Officer, Townsville region)

1.9 List of abbreviations

SLS – Surf Life Saving
PPE – Personal Protective Equipment

1.10 References

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1.11 Consultant qualifications

The consultants contracted for this study are not professional product testers. All effort was made to conduct these tests in as thorough and objective manner as possible, while recognizing our limitations in terms of expertise in engineering and physical properties of materials. We believe these results provide a reliable starting point for development of an Australian Standard for stinger PPE, but ultimately the tests should be conducted by professional product testers and engineers.

1.12 Product endorsement statement

No endorsement of any kind is implied or should be inferred from these tests, except where explicitly stated by the consultants, Surf Life Saving, or James Cook University. These tests were conducted in the interest of scientific enquiry and public safety only, with no commercial contribution of any kind.