C24 Failure Mode Analysis of Resistance Exercise Product Failure Resulting in Eye Injury

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The goal of this presentation is to illustrate how packaging constraints can cause permanent sets in latex tubing thereby shortening the life span of the product, leading to catastrophic failure.

This presentation will impact the forensic science community by illustrating how packaging constraints will have catastrophic effects on the life span and failure mode of some resistance fitness products.

Resistance Band Overview: Resistance bands and tubing are commonly used fitness products on the consumer market. Fitness routines and specific body movements are crafted to focus the workout of certain muscle groups and to enhance overall body strength for specific sporting activities. Resistance exercisers are commonly used for injury prevention and rehabilitation. The benefits of using resistance exercisers for strength training are compelling; they transport easily, take up far less space than a free-weight room, and are affordable compared to monthly gym memberships. The current study closely examines the failure of a resistance exerciser in which a teenager suffered a serious eye injury.

Case Description: The incident occurred at a family fitness center where stretch tubing fitness products were available to its members. A teenager was a member in the studio during a supervised exercise class when the injury occurred. The class instructor demonstrated the use of the resistance exerciser intended for the particular exercise before instructing the class to perform the exercise. The student was performing a leg extension exercise, holding the handle of one end of the exerciser while the student's foot was placed in the loop on the other end, and the exerciser was stretched to provide resistance on leg extension. During one of the repetitions the latex tubing broke and the broken end of the tubing struck the student's eye. The impact caused multiple injuries to the eye, including corneal abrasion, retinal detachment, and a torn retina. As a result of the injury, the student required four surgeries over two years. For unknown reasons, the evidence was discarded by the fitness center personnel.

The resistance exercise products used in the studio were of three distinct designs: a circular shape, or loop, with two foam handles, one opposing the other; a larger loop in a figure-eight configuration with foam handles at either end and third foam cylindrical retainer in the center; and a straight tube with handles at each end (photo 01 figure- eight). All three product designs are constructed of latex tubing, and are offered in five different colors. The tubing color denotes wall thickness, and resistance increases with wall thickness. As the user's muscle strength improves, upgrading to a thicker tubing (different color) will correspondingly increase the resistance of the workout, much like adding more weight to a curling bar.

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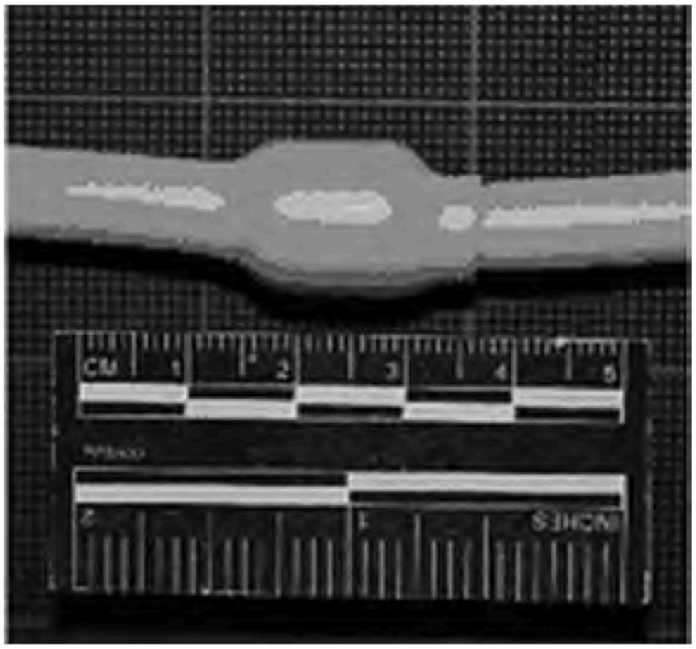
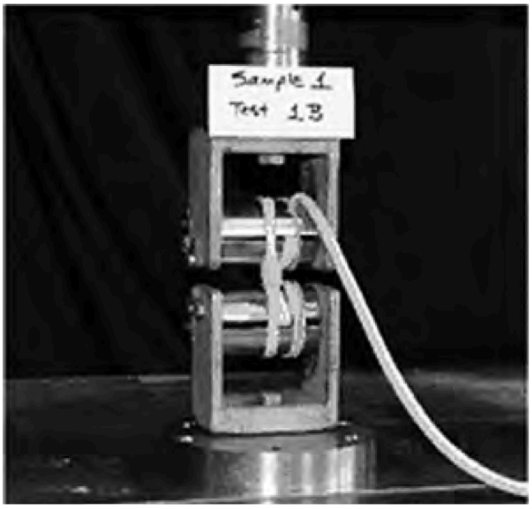
Joint Description/ Failure Mode Hypothesis: The loop and figure eight exercisers feature a joint. The joint does not use adhesive, but rather each end of the tubing is stretched over opposite ends of a solid rubber plug in the shape of a barrel (photo 02 tubing joint). First, one end of the tube is stretched over the plug, and then the other. The overlapping ends of tubing are secured only by friction between the layers. Since the evidence in this case was unavailable to ascertain the failure mode, failure of the joint was proposed as an initial hypothesis. To test this hypothesis, tension tests were conducted on new products to quantify joint design strength.



Tension Testing: Two new, figure-eight exercisers with the same tubing color (0.0625 inch wall thickness) as the one used by the victim were purchased directly from the product manufacturer. A long section of tubing containing the joint and another without the joint were sectioned from each sample. A total of four specimens were tested; two with the joint and two without. An Instron model 1123 tension-compression machine was used. The cut ends of the tubing were held using two inch diameter split-drum grips to reduce the chances of fixture induced stresses (photo 03 joint testing fixture). The crosshead speed (grip separation rate) was ten inches per minute, and data was sampled at 20 Hz.



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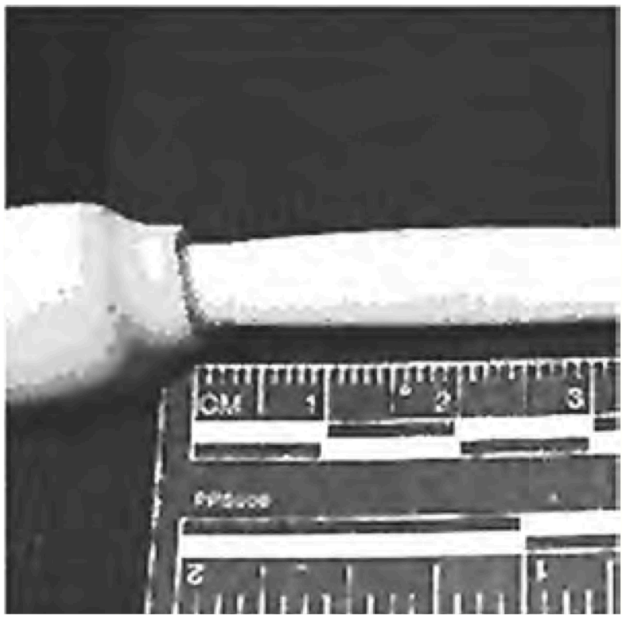
The tubing specimens that did not contain a rubber plug joint were found to break at an average force of about 97 pounds with an average maximum elongation of about 19.0 inches (780%). The tubing specimens that included a joint were found to break at an average force of about 88 pounds with an average elongation of about 19.6 inches (803%). The test results revealed that the rubber plug joint was robust with regard to the test protocol and the tubing failure occurred near the grips. The test failure mode appeared to be induced surface tears resulting from friction where the tubing stretched around the grip or was allowed to contact the tubing secured in the grip's slot. With increased tension, these surface tears grew, causing complete transection of the tubing. The test protocol did not yield insight into the cause of failure of the incident product, because the test failure mode did not replicate the hypothesized failure mode at the joint.

Inventory Inspection: The fitness center resistance product inventory was categorized by design and color, and their storage methods were inspected. Loop, figure-eight and straight exercisers hung from rubber-coated hooks on a wall organizer inside the dojo. Following the inspection of the products actively used by gym members, an inspection of the discarded inventory was also undertaken.

Latex-based resistance exercisers degrade over time. At the time of inspection (2.5 years after the injury), much of the inventory had been taken out of use and maintained by the gym for inspection purposes. Inspection of the discarded inventory identified two areas of latex tubing degradation in the form of surface tears. First, tears were observed adjacent to the joint where the tubing ends were stretched over the rubber plug. The tears were observed to be pulled open by the inherent surface tension caused by the joint design. Second, tears were observed mid- length in the tubing and with higher frequency than those found near the joint (photo 04 tubing tears). These mid-length tears were found to correspond to a permanent set. A permanent set in latex tubing is a defect that is permanent in nature and consists of a kink or fold in the tubing wall caused by bending the tubing below its designed bend radius and maintaining that bend long enough for the tubing to acquire a permanent set. It was hypothesized that these permanent sets causes the propagation of tears, and this was more likely the reason the exerciser broke when used by the victim.



The gym's resistance exerciser inventory was inspected again, this time focusing only on those products hanging on the wall organizer. Remarkably, permanent sets and associated micro-tearing was observed on numerous samples. Even the new products with manufacturing residue on the tubing, not yet removed by use, revealed permanent sets and signs of localized tearing.

Product Packaging: The packaging of the new exercise products purchased was evaluated. The exercisers are placed into compact clear plastic heat-sealed bags with dimensions that guaranteed folding or rolling the product in order to fit. The compact product packing caused permanent sets in the tubing. In fact, permanent sets were observed in the new exercisers inside unopened packages (photo 05 product packaging).

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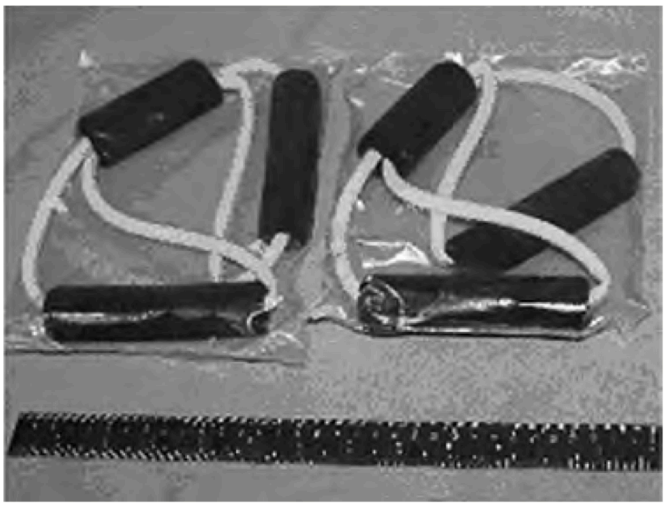

Endurance Testing: Endurance testing was designed to determine if micro-tears associated with permanent sets in the latex tubing would lead to failure of the resistance exerciser. Prior to testing, two specimens were aged in accordance with American Society for Testing and Materials (ASTM) D753-04, Standard Test Methods for Rubber - Deterioration in an air oven. The specimens, maintained in their original sealed bag with air holes, were independently aged at 70°F for 63 and 72 hours, respectively. After aging, the two specimens were inspected and no changes in the tubing were observed.

Each test specimen was then placed in a test device whereby the foam center was placed over a cylinder between two dynamic arms while the two handles were independently secured to fixed arms (photo 06 endurance testing fixture). The dynamic arm would rise approximately 15 inches and then return to the start position where the tubing would rest, thereby completing one cycle. The test and cycle was not intended to simulate any single particular exercise. Rather, the test stretched the exercise product over a modest distance.

In fact, the test did not stretch the product beyond what one would anticipate when adults use the figure-eight exerciser.

Without any tubing surface artifact, the figure-eight would be expected to eventually break after sufficient repetitive cycles of use, because each cycle will naturally cause a minute amount of degradation of tubing material.

Endurance testing was performed at a constant 0.1Hz, and continued until product failure. The first test specimen broke after 1,118 cycles, with complete tubing transection at the location of the deepest permanent set. Testing of the second test specimen was stopped after 2,498 cycles when a deep tear was observed to be forming at one of the permanent sets.

Conclusion: A resistance exercise product failed during use under foreseeable tension forces. Although the product that actually failed was not available for inspection, investigation supported the hypothesis that it failed due to weakness and tearing at a permanent set in the tubing.

The fitness center personnel were remiss in their inspection of the resistance bands products used by gym members.

A permanent set in the tubing is likely to cause incipient tearing that is not perceptible to the user who doesn't know what to look for

(including gym personnel or physical therapists). If a permanent set exists, the tubing will become progressively weaker at this location. The incipient micro-tears will after some period of use suddenly expand and lead to tubing failure.

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It is critical to inspect tubing for permanent sets (under adequate light, using fingers to feel the tubing to detect small tears) before each use. Appropriate warning and instruction should be given to users. Because the risk of sudden failure may not be perceptible, these exercisers should be discarded before incipient tears are permitted to enlarge.

Different packaging is required. Aside from material uniformity (which may vary according to different product processes used by various latex tubing manufacturers), inadequate packaging is a cause of permanent sets in latex tubing. In addition, permanent sets create the risk of failure and injury.

Latex Tubing, Permanent Sets, Resistance Exercise Products

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