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**EFFECTS OF ARCTIC COLD ON SURGICAL AND EXAMINATION GLOVE  
INTEGRITY**

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**United States Army  
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**USARIEM TECHNICAL REPORT T22-05**

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Jason W. Hancock  
Adam W. Potter  
William J. Tharion  
Kristin C. Johnson  
David P. Looney  
Bethany P. Pace  
Xiaojiang Xu  
Reed W. Hoyt

Biophysics and Biomedical Modeling Division

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U.S. Army Research Institute of Environmental Medicine  
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## **EXECUTIVE SUMMARY**

This report is a direct response to a request for information (RFI), "Extreme cold rated disposable medical treatment gloves; (RFI USARAK 21-1, Nitrile/Latex Gloves)" from US Army Alaska (USARAK), via the US Army Combat Capabilities Development Command (DEVCOM) Field Assistance in Science and Technology (FAST) Science Advisor, Mr. Scott Martin.

The ability of US Military medical staff to provide timely and effective trauma care in extreme Arctic cold  $-34.4$  to  $-40^{\circ}\text{C}$  ( $-30$  to  $-40^{\circ}\text{F}$ ) is compromised by breakage of medical treatment gloves. This report provides preliminary assessments of the cold tolerance and durability of four select medical examination gloves following controlled exposure to  $-20$ ,  $-50$ , and  $-80^{\circ}\text{C}$  conditions.

## INTRODUCTION

Climate change continues to increase rates of melting of the northern Arctic ice packs (1), opening up ever greater areas of the Arctic to shipping and exploration (2). Increased activity and ability to travel these areas has inevitably escalated the need for defense and strategic planning to protect national interests and ensure general safety (e.g., search and rescue operations). Operations that must be carried out during the winter months of the Arctic will encounter extreme cold conditions, harsh winter weather, and a general lack of fixed infrastructure (e.g., roads and airstrips) that will compromise the ability for distance traveling and/or potential resupply. Successful military operations in these environments require specialized protective clothing, equipment, and training.

The US military routinely conducts training missions north of the Arctic Circle in the late winter when the cold is at its most extreme. During this period, air temperatures of about  $-40^{\circ}\text{C}$  are common and may be as low as  $-60^{\circ}\text{C}$  (3). These temperature extremes can have significant negative effects on individuals' physical physiological state (4, 5). Additionally, these exposures pose serious threats of cold weather injuries (CWI), that range from non-freezing (e.g., chilblains) and tissue-freezing injuries (e.g., frostbite), to life threatening hypothermia (6, 7). For the US Military, frostbite is the most prevalent CWI (8, 9); where the skin falls to a point at which the tissue begins to freeze. While  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) is the standard freezing point of distilled water; the freezing point of skin is lower than this due to tissue and interstitial electrolyte (4). Dry skin is reported to freeze from  $-4.8^{\circ}\text{C}$  to  $-3.7^{\circ}\text{C}$ , while wet skin will freeze at about  $-0.6^{\circ}\text{C}$  (4, 6).

While military guidance that specifically speaks to the prevention and mitigation of CWI and describes ways to cope with cold weather conditions (i.e., TBMED-508, TRADOC Reg. 350-29) (10, 11), limited published information is available related specifically to casualty care in these extreme temperatures. During these extreme cold conditions, US military medics and medical staff are still required to conduct effective and timely trauma care. However, emergency medical care is impeded by frequent breakage of surgical gloves due to the extreme cold conditions. Current surgical and examination gloves are not rated for use in extreme cold and anecdotal report suggest they often become brittle and break at arctic temperatures. Additionally, manual dexterity is compromised as hand temperature decreases, compromising the Medic's ability to treat casualties (12-14). Proper training, clothing, and operational awareness tools are required to reduce these risks (9, 15-17).

### ***Problem and Objective***

Standard issue nitrile gloves have been found to freeze and break in arctic conditions. Broken gloves in these conditions result in increased risk to both the patient and caregiver. A need was identified for a sterile treatment glove that maintains structural integrity and durability in extreme cold (Arctic) conditions.

A series of ASTM and European Union standards describe methods for evaluating surgical and examination glove performance (e.g., resistance to punctures, etc.) under room temperature conditions (e.g., ASTM D3578-19; ASTM D3577-19; ASTM D7103-19; UNE-EN 455-1; BS EN 455-2:2015). However, no standards exist for testing the integrity of surgical or examination gloves exposed to extreme arctic cold temperatures.

This report in response to a request for information (RFI), “Extreme cold rated disposable medical treatment gloves; (RFI USARAK 21-1, Nitrile/Latex Gloves)” from US Army Alaska (USARAK), via the US Army Combat Capabilities Development Command (DEVCOM) Field Assistance in Science and Technology (FAST) Science Advisor. This report describes the effects of exposure to extreme cold on the integrity of nitrile and neoprene surgical and examination gloves.

## METHODS

A series of eight cold tolerance tests were conducted on four different gloves, three sterile surgical gloves and one non-sterile examination glove. The four types of gloves (Table 1) were exposed to -20, -50, and -80°C in a laboratory freezer for periods ranging from 2 to 24 h. Durability tests, described below, immediately followed cold exposure.

### Materials

**Table 1.** Manufacturer and description of four gloves that were tested.

	<b>Ansell GAMMEX</b>	<b>Biogel® NeoDerm</b>	<b>Biogel® Skinsense</b>	<b>Halyard</b>
<b>Feature</b>	Non-Latex Neoprene	Neoprene	Neoprene	Nitrile; Dental Exam Glove
<b>Sterile / Non- Sterile</b>	Sterile	Sterile	Sterile	Non-Sterile
<b>Color</b>	Green	Brown	Yellow	Purple
<b>Thickness</b>	4-5 mils	8.7 mils	8.3 mils	5.3 mils
<b>NSN</b>	6515-00- NIB-0134	6515-00- NIB-0656	6515-00- NIB-0394	N/A

### Cold Tolerance Tests

A series of eight tests were conducted to assess the wet and dry cold tolerance (Tests 1 and 2), wear durability (Test 3), and durability (Tests 4-8). Figures 1 and 2 show the gloves prior to entry and entry into the freezer; while Table 2 provides a summary of each of these tests and more detailed descriptions are below.

For the wet and dry cold tolerance tests, each glove was either filled with water and tied closed (“wet” Test 1) or kept dry (“dry” Test 2). The gloves were then placed

flat in a  $-80^{\circ}\text{C}$  freezer and left untouched. After 24 hours, the gloves were carefully taken out of the freezer and allowed to thaw at room temperature. Visual and manual assessments were made to determine if the gloves had leaks or breakages. Gloves that developed leaks or breaks at any time during this assessment were considered to have failed the test.

The wear durability test (Test 3) involved placing dry gloves in a freezer set to  $-80^{\circ}\text{C}$  for 24 hours. Immediately following removal from freezer, gloves manually compressed 3 times, then filled with room temperature water, tied closed, and assessed. Gloves that developed leaks or breaks at any time during this assessment were considered to have failed the test.

For the durability tests (Tests 4-8), gloves were placed dry in the freezer set to one of three temperatures ( $-80$ ,  $-50$ , or  $-20^{\circ}\text{C}$ ) and remained undisturbed for either 2 or 24 hours. Immediately following removal from freezer, the frozen gloves were manually compressed three times then filled with tap water ( $\sim 20^{\circ}\text{C}$ ), tied closed, and assessed. Gloves that developed leaks or breaks at any time during this assessment were considered to have failed the test.

**Figure 1.** Gloves at entry into freezer



**Figure 2.** Gloves prior to freezer entry



**Table 2.** Summary of test conditions

Test	Assessment	Time (h)	Ta (°C)	Short Description of Steps
1	Cold tolerance	24	-80	Water filled. Freeze. Thaw. Inspect.
2		24	-80	Dry freeze. Fill with water. Inspect.
3	Durability (donned)	24	-80	Dry freeze. Don glove and clench fist (x3). Fill with water. Inspect.
4	Durability	2	-80	Dry freeze. Compress in clenched fist (x3). Fill with water. Inspect.
5		2	-20	Dry freeze. Compress in clenched fist (x3). Fill with water. Inspect.
6		24	-20	Dry freeze. Compress in clenched fist (x3). Fill with water. Inspect.
7		2	-50	Dry freeze. Compress in clenched fist (x3). Fill with water. Inspect.
8		24	-50	Dry freeze. Compress in clenched fist (x3). Fill with water. Inspect.

## RESULTS

All the gloves tested passed Test 1 (fill with water, place in freezer at  $-80^{\circ}\text{C}$  for 24 h, remove, thaw, assess integrity), and Test 2 (dry freeze at  $-80^{\circ}\text{C}$  for 24 h, thaw, fill with water, inspect integrity). None of the gloves passed Test 3 (freeze dry at  $-80^{\circ}\text{C}$  for 24h, remove and don, form a fist three times, fill with water, inspect for leaks) or Test 4 (freeze dry at  $-80^{\circ}\text{C}$  for 2 h, remove, compress in fist 3 times, fill with water, inspect). Notably, the Halyard nitrile gloves in Test 4 were rigid (frozen) following removal from the freezer; while the other three types of neoprene gloves remained pliable (unfrozen). All of the gloves passed the durability compression test following dry exposure to  $-20^{\circ}\text{C}$  for 2 and 24 hours (Test 5 and 6). Only the Halyard Nitrile and Ansell Gammex gloves passed the durability test at  $-50^{\circ}\text{C}$  for 2 hours (Test 7). The Halyard nitrile glove was the only one that passed the extended durability test at  $-50^{\circ}\text{C}$  for 24 h. Table 3 summarizes these test results. Figures 3 and 4 show the gloves prior removal from the freezer and immediately following removal from the freezer. Additional figures of the commonly found integrity failures (breaks, holes, rips) are shown in Appendix A.

**Table 3.** Summary of test results

Test	Assessment	Time (h)	Ta ( $^{\circ}\text{C}$ )	Ansell GAMMEX	Biogel® NeoDerm	Biogel® Skinsense	Halyard
1	Cold tolerance	24	$-80$	Pass	Pass	Pass	Pass
2		24	$-80$	Pass	Pass	Pass	Pass
3	Wear durability	24	$-80$	Fail	Fail	Fail	Fail
4	Durability	2	$-80$	Fail	Fail	Fail	Fail
5		2	$-20$	Pass	Pass	Pass	Pass
6		24	$-20$	Pass	Pass	Pass	Pass
7		2	$-50$	Pass	Fail	Fail	Pass
8		24	$-50$	Fail	Fail	Fail	Pass

**Figure 3.** Water filled and dry gloves prior to removal from  $-80^{\circ}\text{C}$  freezer.



**Figure 4.** Water filled gloves upon removal from  $-80^{\circ}\text{C}$  freezer.



## DISCUSSION

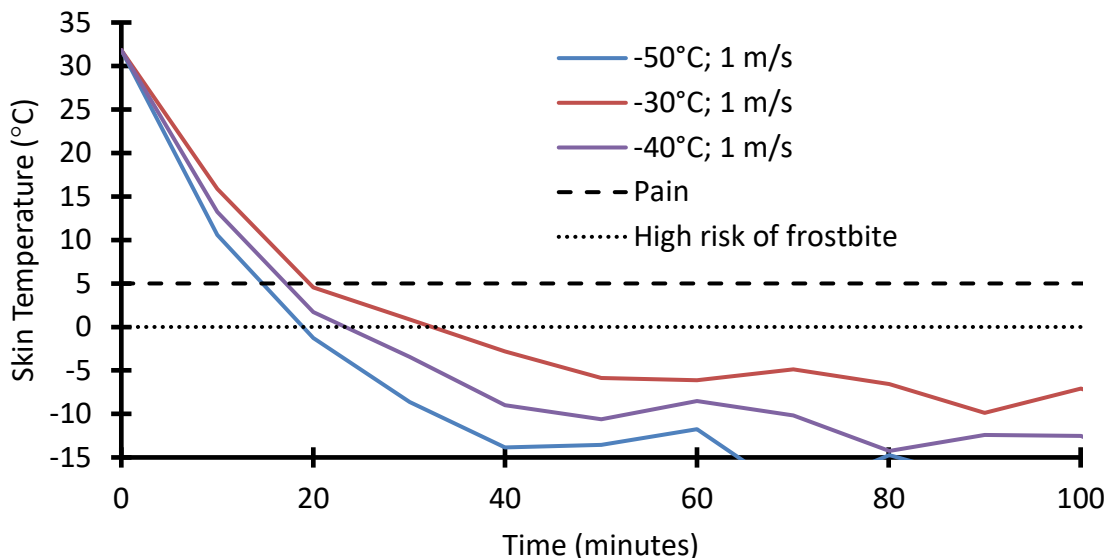
Glove storage and handling prior to use can become a confounding element with respect to glove integrity. Gloves stored in cold conditions (e.g., Arctic conditions) can more quickly become fragile and therefore should be handled with care in order to thaw them prior to use. Anecdotal 'common' practices from the field have tended to keep the gloves tucked away on the body between layers of clothing to keep them readily accessible and thawed prior to use. However, if this process cannot be achieved then it is important to note an alternative method(s) should be used and assessed for bringing or maintaining gloves at an acceptable temperature prior to use. From the work in this report, if necessary nitrile gloves may be safe to use even in fairly extreme cold conditions (e.g., warmer than  $-50^{\circ}\text{C}$ ).

Construction and material makeup of the gloves tested provides an important indicator to their overall performance. From the assessments, the thicker gloves tended to break down more readily after exposure to  $-50^{\circ}\text{C}$ . In contrast, the Ansell Gammex, which was the thinnest neoprene glove tested, was generally more durable, possibly

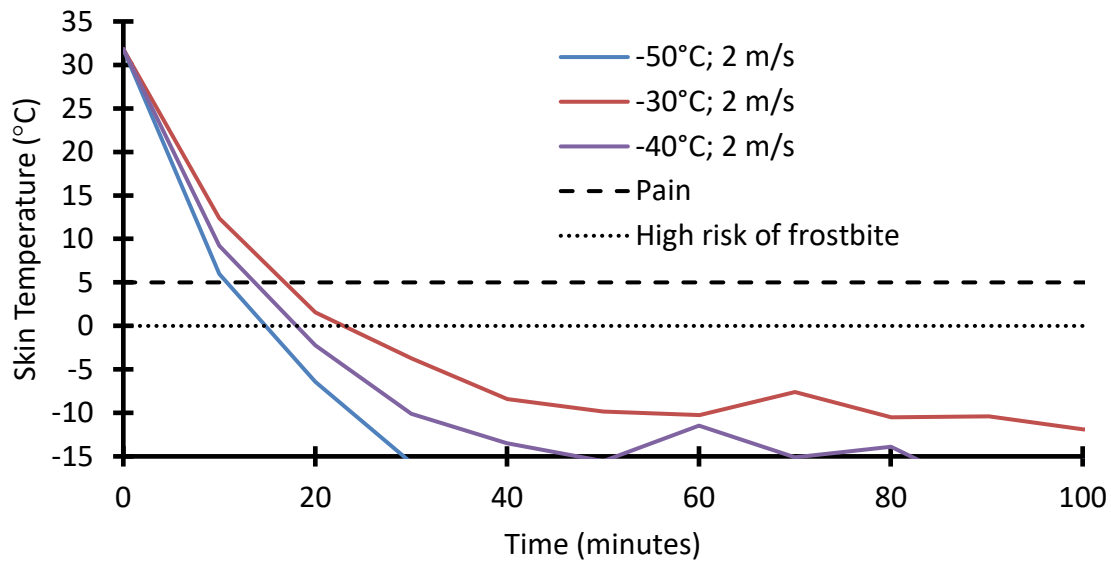
because it thawed more readily than the heavier gloves. Nitrile rubber materials typically contain ~18% percent acrylonitrile maintain good low temperature flexibility down to about  $-48^{\circ}\text{C}$  (18). The nitrile glove we tested may have had sufficient acrylonitrile to withstand low temperatures. However, manufacturers are generally unwilling to share their glove's chemical composition.

Medics wearing standard medical treatment gloves while treating casualties in extreme cold conditions are likely to experience decreases in manual dexterity and tactile sensitivity due to rapidly decreasing hand temperatures. Current modeling suggests that frostbite in these extreme cold conditions will occur less than 20 minutes without any hand protection. Modeling predicts that under extreme cold conditions, hand temperature will drop to  $15^{\circ}\text{C}$  ( $59^{\circ}\text{F}$ ) in less than 10 min, and to  $5^{\circ}\text{C}$  ( $41^{\circ}\text{F}$ ) in less than 20 min. Hand temperatures of  $15^{\circ}\text{C}$  are associated with a loss of coordination and performance; while at  $5^{\circ}\text{C}$ , hands become extremely painful and complicated manual tasks cannot be accomplished. This predicted time course of hand cooling assumes the person was in a warm built space before going out into the cold. If the person is already cold, then endurance may be shortened significantly to reach  $15^{\circ}\text{C}$  ( $< 5$  min) and  $5^{\circ}\text{C}$  ( $< 10$  min). Predicted uninsulated hand skin temperature responses to arctic cold in individuals wearing no hand thermal protection, and who are engaged in a low-to-moderate level of physical activity ( $173\text{W}$ ; 1.5 MET), are shown in Figures 5 and 6. Figure 5 shows simulated responses to  $-30$ ,  $-40$ , and  $-50^{\circ}\text{C}$  in low wind (1 m/s; 2.2 mph). Loss of manual dexterity occurs within 10 min, pain occurs at about 15-to-20 min, and high risk of frostbite occurs at 20-to-35 min. Figure 6 shows even more rapid progression from loss of manual dexterity to pain and then high risk of frostbite when individuals are exposed to  $-30$ ,  $-40$ , and  $-50^{\circ}\text{C}$  in moderate wind (2 m/s; 4.5 mph) conditions.

**Figure 5.** Modeled hand skin temperature responses to extreme cold in low wind conditions (1 m/s) and low activity ( $173\text{W}$ )

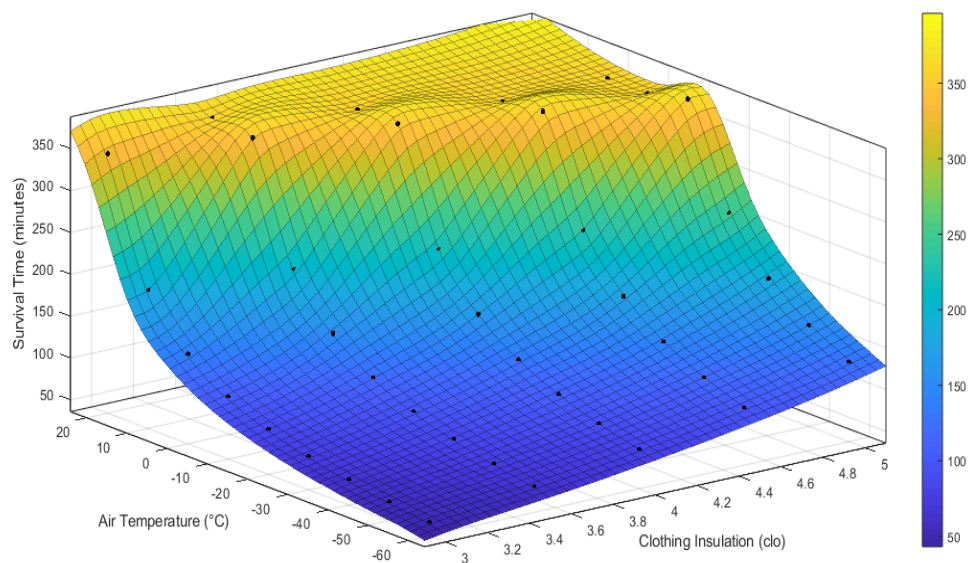


**Figure 6.** Modeled hand skin temperature responses to extreme cold in moderate wind conditions (2 m/s) and low activity (173W)



Additionally, while the glove tolerance and durability is important, it is also critically important to recognize the whole human element. Simply stated, without adequate clothing in these extreme cold conditions risks of injury and potential death can be significant and can occur relatively quickly. For context, data collected and reported by Santee (19) was used to create fourth order polynomials and a surface plot of survival time (in minutes), as a function of environmental temperature ( $^{\circ}\text{C}$ ) and clothing insulation (clo) at rest (1 MET) (Figure 7). From this empirically derived plot, we can see that inadequate clothing insulation significantly affects survival at rest (Figure 7).

**Figure 7.** Surface plot of survival at rest as a function of air temperature ( $^{\circ}\text{C}$ ) and clothing insulation (clo)



Current sterile nitrile/neoprene medical exam/treatment gloves are not rated for use in extreme cold, and may become brittle and break at low temperatures. Low temperature nitrile rubber formulations exist, but an initial survey of available gloves did not find sterile medical treatment gloves made with low temperature nitrile. To improve durability, it may be possible to obtain sterile nitrile/neoprene gloves that are thicker than typical medical treatment gloves (e.g., 14 mil vs 5 mil), but the increased thickness, as shown in the tests within this report, may result in unacceptable degradation in dexterity and tactile sensitivity, and the standard nitrile formulation may still be vulnerable to breakage. While the results from this study indicate there may be a potential solution that will remain durable in these cold conditions; the need for maintaining an acceptable level of cold protection is still a gap. Therefore, the development of new DoD-approved medical treatment gloves suitable for use in extreme cold may be needed.

There are several limitations to the present assessments. Most importantly, given the complexity of real-world activities, we recognize that the assessments performed do not exactly reflect the potential stress imposed on these gloves in a field environment. Nevertheless, the present tests were developed as a way of imposing a controlled level of cold stress and durability that could be translated to most activities expected to occur during medical use cases. With all of the assumptions outlined in this report, these results suggest that the conditions for durability assessment from Test 7 ( $-50^{\circ}\text{C}$ ) are adequate for assessing glove durability related to the current demands. However, it is important to note, that while the effects of moderate cold exposure on human thermal responses has been modeled extensively (16, 20-22), a need exists to gather more data on human responses to extreme arctic cold exposure to enable improvements to predictive and improve safety criteria for Arctic training and operations.

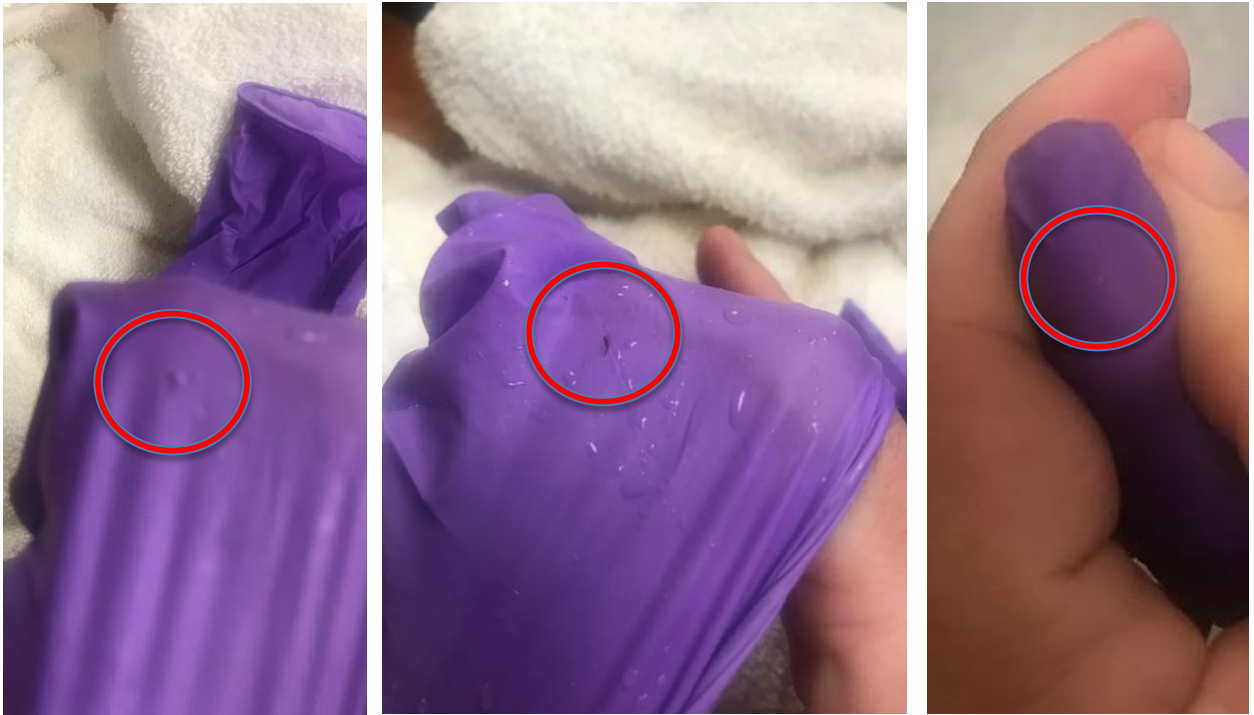
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## APPENDIX A. Images of common integrity failures

### Halyard Nitrile



**Ansell Gammex**



**Biogel® Skinsense**



**Biogel® NeoDerm**

