

# Development of a Methodology for Characterizing Commercial Chlorinated Latex Gloves

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**ABSTRACT:** Chlorination of gloves has gained popularity as a more permanent method of reducing the inherent tackiness of natural rubber latex compared to using powder as a dusting lubricant. Transmission of proteins in natural rubber latex into the air as a result of using powder on natural rubber latex gloves may cause serious complications to allergic individuals. A methodology for characterizing commercial chlorinated natural rubber latex gloves using a combination of attenuated total reflectance (ATR)–Fourier transform infrared (FTIR) spectroscopy and ion chromatography (IC) is described. ATR–FTIR studies established that 930–915 and 670–650  $\text{cm}^{-1}$  are definitive wavenumber ranges for the identification of chlorine in commercial chlorinated latex gloves. Confirmation of the ATR–FTIR results and semiquantification of the chlorine content in the latex gloves was carried out by the IC technique. This methodology can be used by glove manufacturers to determine the amount of chlorine in batches of commercial gloves, and thereby prevent possible threats to public health arising from the deterioration of surgical and examination chlorinated latex gloves under severe storage conditions before the end of their expected shelf life. © 2001 John Wiley & Sons, Inc. *J Appl Polym Sci* 82: 672–682, 2001

**Key words:** natural rubber latex; glove; chlorination; methodology; infrared spectrometry; ion chromatography

## INTRODUCTION

One of the major sources of latex allergy is from powdered natural rubber latex gloves. Natural rubber proteins bound to airborne glove powder are known to cause respiratory complications for individuals allergic to natural rubber latex, abbreviated in this report as “latex.”<sup>1,2</sup> Although the use of glove powder as a dusting lubricant to reduce the inherent tackiness of natural rubber is

still in practice, there is an increase in the demand for powder-free latex gloves, in particular, chlorinated latex gloves, not just in the United States but also worldwide. Compared to dusting powder, which may come off during use, chlorination is a more permanent method of reducing surface drag and enhancing smoothness of the product surface.<sup>3–5</sup> Aziz found that surface morphology and physical properties (e.g., tensile strength) are compromised by chlorinating latex gloves.<sup>5</sup> This may result in the reduction of shelf life, grip, and in-use durability.<sup>3</sup> Chlorination beyond the optimum level has led to cases of skin irritation among users and development of strong

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odors. A more serious issue is that there is world-wide concern that the usage of deteriorated surgical and examination gloves can be a severe threat to public health because of the transmission of pathogens. Thus, the chlorination process for latex gloves needs to be tightly controlled.

Romberg found that chlorination had a drastic effect on the physical structure of the glove surface besides changing the chemical functionality of the surface.<sup>4</sup> Romberg's studies revealed that, because of the effect of chlorination, cracks developed on the surface of the glove. The effect of chlorination on both unaged and aged glove samples was studied.<sup>5</sup> The tensile strength of chlorinated glove samples of both types was found to decrease significantly at 0.3% concentration for the chlorinating solution compared to concentrations of 0.01, 0.03, 0.05, and 0.1%, respectively. Decreases of 9 and 34% in the tensile strength were observed after 1 and 20 min, respectively, of chlorination time using a 0.3% solution compared to the tensile strength using a 0.1% solution. Moreover, scanning electron microscopy (SEM) studies<sup>4,5</sup> revealed that an increase in the chlorine content in the glove sample leads to the appearance and enlargement of cracks, and causes the material to exhibit brittleness. Oldfield and Symes<sup>6</sup> conducted X-ray fluorescence (XRF) studies to calculate the chlorine content (% w/w) on the surface of a natural rubber (NR) sample, thickness less than 5  $\mu\text{m}$ , assuming one atom of chlorine has been added for each double bond in the polymer.

Based on the XRF results, it was found that by increasing the concentration of the organic chlorinating agent, trichloroisocyanuric acid (TCICA), from 0.1 to 0.2%, the chlorine content on the NR surface increased 10-fold, from 0.2 to 2.0% w/w. Furthermore, by increasing the concentration of the TCICA chlorinating solution from 0.2 to 0.4%, the chlorine content increased from 2.0 to 4.2% w/w, approximately twofold. This is an important observation, even though the assumption of one chlorine atom being added to each double bond in the latex polymer is unrealistic. The XRF studies showed that by increasing the concentration of the chlorinating solution from 0.1 to 0.4% resulted in an appreciable increase, approximately 20-fold, in the chlorine content on the NR surface. Hence, for a concentration of the chlorinating solution of 0.3%, the actual chlorine content on the NR surface would be much higher. These findings from XRF studies for the NR sample in combination with the SEM results for the natural rubber

latex glove samples<sup>4,5</sup> may suggest that as a result of the sharp increase in the chlorine content in the glove surface at 0.3% concentration of the chlorinating solution, significant development and enlargement of superficial cracks may occur compared to lower chlorinating solution concentrations (<0.3%). Such cracks may cause a substantial decrease in the tensile strength of the natural rubber latex glove samples. Under extreme storage conditions where the temperature is high (e.g., in a tropical or arid climate), these cracks may propagate more, leading to severe degradation. Use of these deteriorated gloves could be a severe threat to public health because of the possibility of pathogens being transferred, particularly during surgical operations.

The Center for Devices and Radiological Health (CDRH) at FDA, along with numerous other organizations sponsored a satellite broadcast in May 1998, in the United States and Canada, on "Natural Rubber/Latex Allergy: Recognition, Treatment, and Prevention." An overview on this nationwide conference stated that

[N]atural rubber/latex allergy is an emerging public health issue which impacts a wide range of health care and workplace procedures and practices. Allergy to natural rubber/latex containing materials can result in serious health problems. Health care providers using natural rubber latex products, particularly protective gloves, need to know how to minimize the possibility that they or their patients may become sensitized.

Developments in chlorination technology for latex gloves have been aimed to minimize this problem.

Chlorination of latex rubber gloves is performed by immersing the gloves in a dilute chlorine solution. The chlorine solution could be prepared either by dissolving chlorine gas directly into water or by reacting a solution of hypochlorite with hydrochloric acid. The chlorine reacts with the natural rubber surface to reduce the inherent tackiness of the latex, hence eliminating the need to add a donning powder to the glove.<sup>3,4</sup> After immersion of the glove into the dilute chlorine solution (usually between 0.05 to 0.3 wt %), the gloves are washed in water, dipped in a neutralizing solution (e.g., ammonia solution), rinsed again, and then dried.<sup>4,5</sup>

Fourier transform infrared (FTIR) spectroscopy was previously used for the study of chlorination in latex rubber gloves.<sup>4,6-9</sup> Attenuated total reflectance (ATR) spectroscopy, a versatile and powerful technique in infrared sampling, in com-

bination with FTIR, has confirmed the formation of allylic chlorides resulting from aqueous chlorination of natural rubber.<sup>4,6,8</sup> The presence of chlorine in the surface regions of chlorinated natural rubber samples was detected by ATR-FTIR.<sup>8</sup> In our study, the ATR-FTIR technique was used primarily because the glove sample was too thick to analyze reliably by transmission FTIR techniques.

According to Romberg,<sup>4</sup> the infrared spectroscopic identification of the chlorination in the isoprene units of natural rubber samples is attained by the presence of absorbance peaks at 1260  $\text{cm}^{-1}$  (H-rock on H—C—Cl), 915  $\text{cm}^{-1}$  (Cl-stretch on Cl—C—C), and 800  $\text{cm}^{-1}$  (Cl-stretch on Cl—C—H). Romberg<sup>4</sup> studied polyisoprene, chlorinated in hexane, and cured natural rubber surfaces using a Wilks 4-mirror ATR attachment with a  $10 \times 52\text{-mm}$  trapezoidal KRS-5 crystal with  $45^\circ$  faces. Extrand and Gent<sup>8</sup> performed IR spectroscopy of natural rubber surface regions with a Beckman Model 2100 FTIR spectrophotometer (Beckman Instruments, Palo Alto, CA), using a spectrograph ATR attachment. Samples were placed on both sides of a thallium bromide/iodide crystal to give a total of 14 reflections.

Extrand and Gent<sup>8</sup> reported that spectra obtained from chlorinated materials were quite complex and quite different from those of nonchlorinated samples. It was also documented that bands that can be specifically assigned to chlorine appeared at 1260, 750, and 660  $\text{cm}^{-1}$ . In addition, three unassigned bands that are almost certainly attributable to chlorine were found at 1410, 915, and 780  $\text{cm}^{-1}$ . Extrand and Gent suggested provisional assignments for chlorinated natural rubber. The peak at 1410  $\text{cm}^{-1}$  was ascribed to Cl-influenced sidechain  $\text{CH}_2$  bend (functional group:  $-\text{CH}_2-\text{Cl}$ ), the peak at 1260  $\text{cm}^{-1}$  was assigned to Cl-influenced allylic C—H bend (functional group:  $=\text{C}-\text{C}-\text{H}$ ), and the peaks at 915 and 780  $\text{cm}^{-1}$  were ascribed to olefinic C—Cl stretch (functional group:  $=\text{C}-\text{Cl}$ ). Oldfield and Symes<sup>6</sup> used internal reflection (IR) spectroscopy on a Perkin-Elmer 580B computer-assisted IR spectrophotometer (Perkin Elmer Cetus Instruments, Norwalk, CT) using a germanium crystal. Oldfield and Symes found that in natural rubber, which is a chemically homogeneous polymer comprising primarily (more than 98%) *cis*-polyisoprene, the changes on the surfaces upon chlorination were associated with a decrease in the absorbance at 900  $\text{cm}^{-1}$  attributed to the *cis* double bond and the appearance of a new absorbance

peak at 835  $\text{cm}^{-1}$  ascribed to a pendant double bond.

In addition to these assignments, the presence of a peak ascribed to the C—Cl vibrational stretch at 670  $\text{cm}^{-1}$  was found for chlorinated rubber and at 665  $\text{cm}^{-1}$  for polychloroprene<sup>10</sup> and supported by a typical assignment of the absorption ascribed to the C—Cl stretching vibrations<sup>11</sup> indicative of the aliphatic, chlorinated compounds found at around 665  $\text{cm}^{-1}$ . Furthermore, it is stated in the Omnic Interpretation Guide, Version 1.0 (Nicolet Instruments, Madison, WI), that characteristic absorptions shown by Cl compounds in the mid-infrared region arise from the C—Cl stretching vibrations between 760 and 650  $\text{cm}^{-1}$ .<sup>11</sup> Combining all these chlorine-related assignments, the wavenumbers (ranges) of interest are 1410, 1260, 915, 900, 835, 800–750, and 670–650  $\text{cm}^{-1}$ .

Developments over the years have made ion chromatography (IC) a convenient methodology for determination of chloride anion content.<sup>12</sup> The invention of suppressed ion chromatography was the turning point that made ion chromatography the dominant method for inorganic anion analyses. In our study, the scheme proposed by Romberg<sup>4</sup> was followed to strip the chlorine from the chlorinated rubber glove samples. According to this scheme, a known weight of the sample was placed in a known volume of deionized water in a container with lid and heated to 120°C (248°F) for 20 min. According to Romberg, this will result in the loss of allylic chlorides from the polyisoprene backbone structure of the natural rubber samples. IC methodology can then be used to separate the chloride anions by their characteristic rate of migration down the anion exchange resin. In our study, a semiquantification methodology for determining the chlorine content in commercial natural latex glove samples was developed using IC.

## EXPERIMENTAL

### Rubber Samples

Four different brands of latex gloves were studied. The samples tested were coded as follows:

1. Manufacturer A Chlorinated Latex Glove
2. Manufacturer B Chlorinated Latex Glove
3. Manufacturer C Powder-Free Chlorine-Free Latex Glove (Negative Control)
4. Manufacturer D Powdered Chlorine-Free Latex Glove (Negative Control)

In addition, polychloroprene (Lot No. 10603TR; Aldrich Chemical, Milwaukee, WI) was also studied. A polychloroprene chunk was sliced to the approximate thickness of an examination glove for the ATR-FTIR spectroscopic study.

### ATR-FTIR Spectrometry Studies

For ATR-FTIR studies, analysis was performed on a SpectraTech Baseline Horizontal ATR (HATR) accessory with a multibounce (12 reflections) ZnSe crystal at an angle of incidence of  $45^\circ$  that was installed in a Nicolet 20SXB FTIR spectrometer. The attachment was equipped with a flat plate and a gripper. The conditions used for the study were as follows: resolution =  $4.0\text{ cm}^{-1}$ , sample gain = 4.0, data spacing  $1.928\text{ cm}^{-1}$ , mirror velocity = 0.7912, and aperture = 79. Happ-Genzel apodization was used. The approximate depth of penetration was calculated to be  $2.0\text{ }\mu\text{m}$  at  $1000\text{ cm}^{-1}$ . The optical unit of the Baseline HATR contains the mirrors that direct the infrared beam through the sample onto the detector. It is baseplate mounted and was used with the flat sampling plate. The flat plate used for this study was a Teflon-coated aluminum plate in which the surface of the mounted ZnSe ATR crystal is level with the surface of the plate of the rubber glove (film) samples. The MINIGRIP was mounted onto the top plate with two screws. Scanning was done over the spectral range of  $4000\text{ to }650\text{ cm}^{-1}$ . Omnic Software version 1.10 was used for the FTIR spectral analysis.

Strict sample handling procedures were followed to conduct the ATR-FTIR runs. Because the pressurized MINIGRIP assembly is designed to ensure very close contact between the glove sample and the ZnSe ATR crystal, the possibility of sample contamination was minimized. Before each run, the ZnSe crystal was cleaned with 99.9+% methanol (Burdick and Jackson, Muskegon, MI) and air-dried for 2 min. High-purity acetone may also be used for cleaning the ZnSe crystal. For the negative control latex glove samples, spectra were recorded for both unwashed samples and samples washed with 200 mL 18-M $\Omega$  reagent-grade water from the Millipore Milli-Q UV PLUS water-filtration system (Millipore, Bedford, MA).

### Ion Chromatography Studies

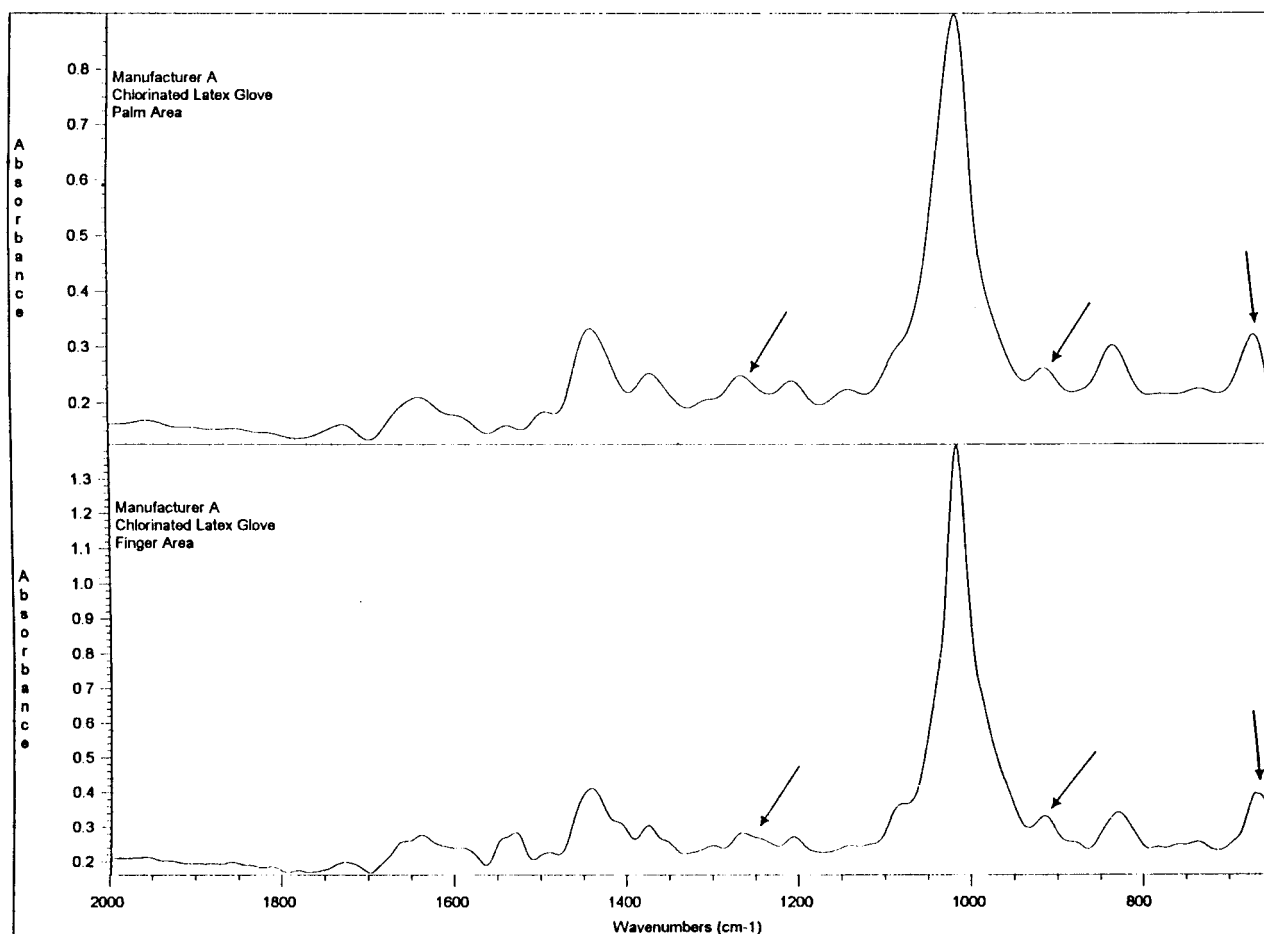
A Dionex Series 4500i Ion Chromatography System equipped with an anion micromembrane sup-

pressor (S/N 10089), an eluant degassing module, a gradient pump system, an inert rotary valve manual injection system, a conductivity detector, a Perkin-Elmer LC-100 laboratory computing integrator, and a Dionex AS4A 4 mm (10-32) resin column (S/N 33268) were used for this study. The flow rate was 1.0 mL/min; the injection loop, 50  $\mu\text{L}$ ; output range, 100  $\mu\text{S}$ ; and the total run time, 5 min. The eluant solution used for this study was prepared by adding 0.2856 g of sodium bicarbonate (1.7 mM) and 0.3816 g of sodium carbonate (1.8 mM) into a 2000-mL volumetric flask and bringing it up to volume with 18-M $\Omega$  reagent-grade water.<sup>13</sup> The sodium bicarbonate (Lot No. 7412) and the sodium carbonate (Lot No. 7512) used were both of analytical reagent grade purchased from Mallinckrodt (Paris, KY). The flask was shaken thoroughly for 20 min to allow dissolution and homogeneous mixing. The regeneration solution for the micromembrane suppressor was prepared by adding 1.4 mL of 36N sulfuric acid into a 2000-mL volumetric flask and by bringing it up to volume with reagent-grade water to produce 0.025N sulfuric acid solution.<sup>13</sup> The flask was shaken thoroughly for 20 min to allow dissolution and homogeneous mixing. Both solutions were filtered through 0.45- $\mu\text{m}$  membrane filters before use.

For each of the four brands of gloves, approximately 0.03 g of sample was weighed out accurately using a Sartorius Research balance (FDA No. 781033) into a 15-mL test tube with Teflon-lined screw cap. Reagent-grade water (10 mL) from the Millipore Milli-Q UV PLUS water-filtration system was added to the test tube. It was ensured that the glove sample had intimate contact with water. The test tubes were placed in a tube rack and heated in a Market Forge Sterimatic Autoclave (FDA No. 5007996) system preset at  $250^\circ\text{F}$  for 20 min. The resulting solution containing chloride ion for each of the glove samples was injected into the Dionex IC system through a Titan Filtration System 0.45- $\mu\text{m}$  nylon-membrane filter (Lot No. 803239024052).

The Dionex 4500i IC System was calibrated by performing a linearity test using NaCl volumetric standard solution in water (Lot No. 01502TR) purchased from Aldrich. Five concentrations of the NaCl solution were prepared for the calibration test: 0.5, 1.0, 1.5, 2.0, and 5.0  $\mu\text{g/mL}$ . The chloride anion peaks for triplicate runs for each of the concentrations exhibited an overall mean retention time of 3.31 min with an overall standard deviation of 0.01. Excellent correlation ( $R^2$  value





**Figure 1** ATR-FTIR spectra of the palm area (top) and the finger area (bottom) for the Manufacturer A chlorinated natural rubber latex glove.

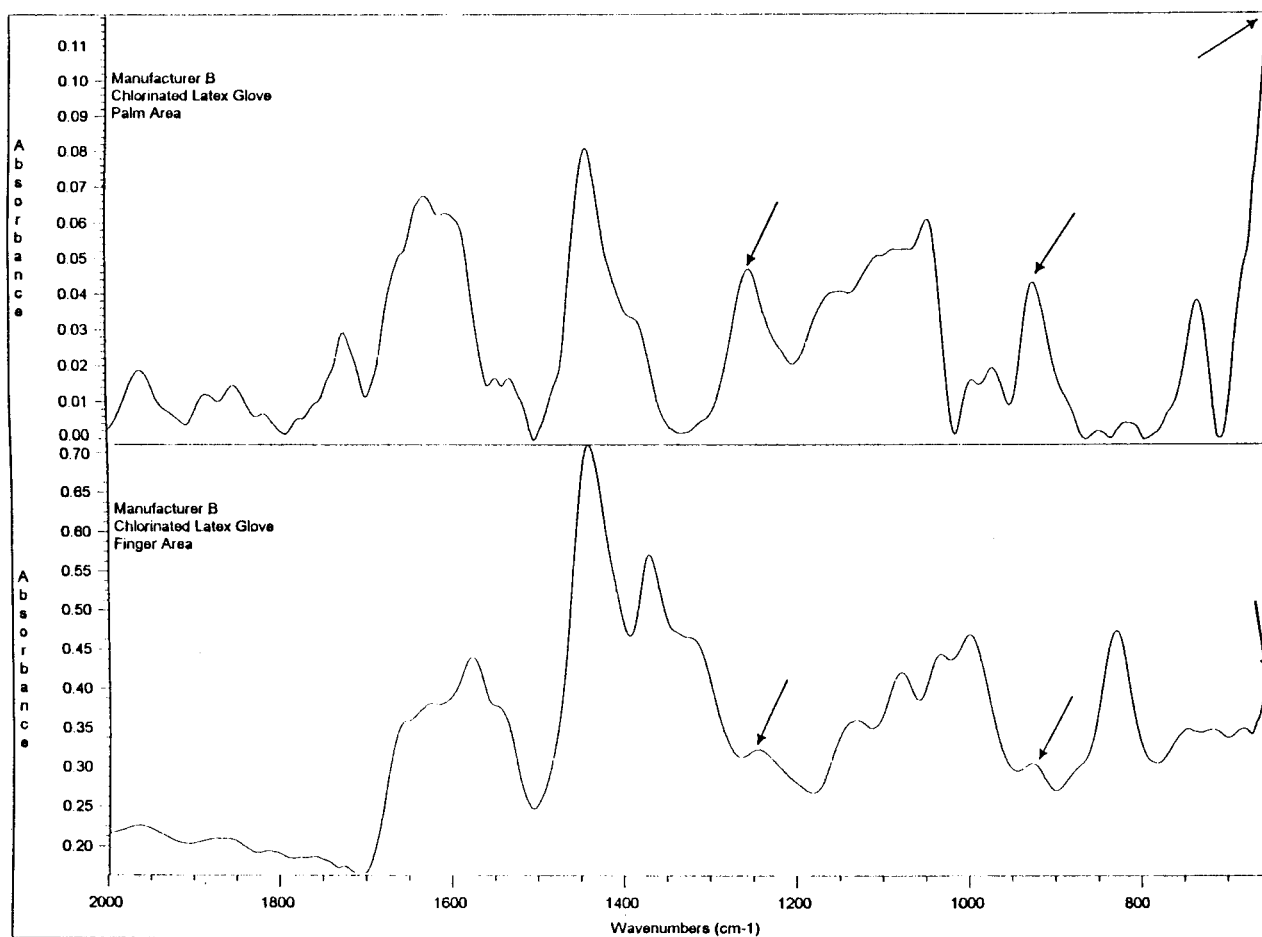
of 0.995) for the ion chromatograph data was obtained for the linearity test, confirming the successful calibration of the instrument.

## RESULTS AND DISCUSSION

### ATR-FTIR Spectrometry

As mentioned earlier in the introductory remarks, the chlorine-related wavenumbers (ranges) of interest are 1410, 1260, 915, 900, 835, 800–750, and 670–650  $\text{cm}^{-1}$ . A detailed spectral comparison between the palm area and the finger area for the two chlorinated latex glove samples was conducted in triplicate to investigate the variation in the chlorine content in these samples, as shown by the ATR-FTIR spectra. Representative IR spectra, each for the palm area and the finger area, of the two chlorinated glove samples, Manufacturers A and B, are shown in Figure 1

and Figure 2, respectively. Both brands of gloves, especially those of Manufacturer B, exhibited differences in the IR spectra for the palm area compared to that for the finger area. The assignments used for the chlorine-related peaks in natural rubber by Romberg,<sup>4</sup> Gent and Extrand,<sup>8</sup> and Oldfield and Symes<sup>6</sup> were verified to determine definitive and consistent absorption band assignments that can be adopted for identification of chlorination in latex gloves. To achieve this goal, comparisons were made between the two chlorinated glove samples (Manufacturer A versus Manufacturer B) as shown in Figure 3, and between a representative chlorinated glove (Manufacturer B) and chlorine-free gloves (negative control samples), as shown in Figure 4. Spectral analyses and interpretations were conducted by calculating ratios of the peak height under IR absorbance peaks from signatures obtained that are primarily chlorine related to the peak height



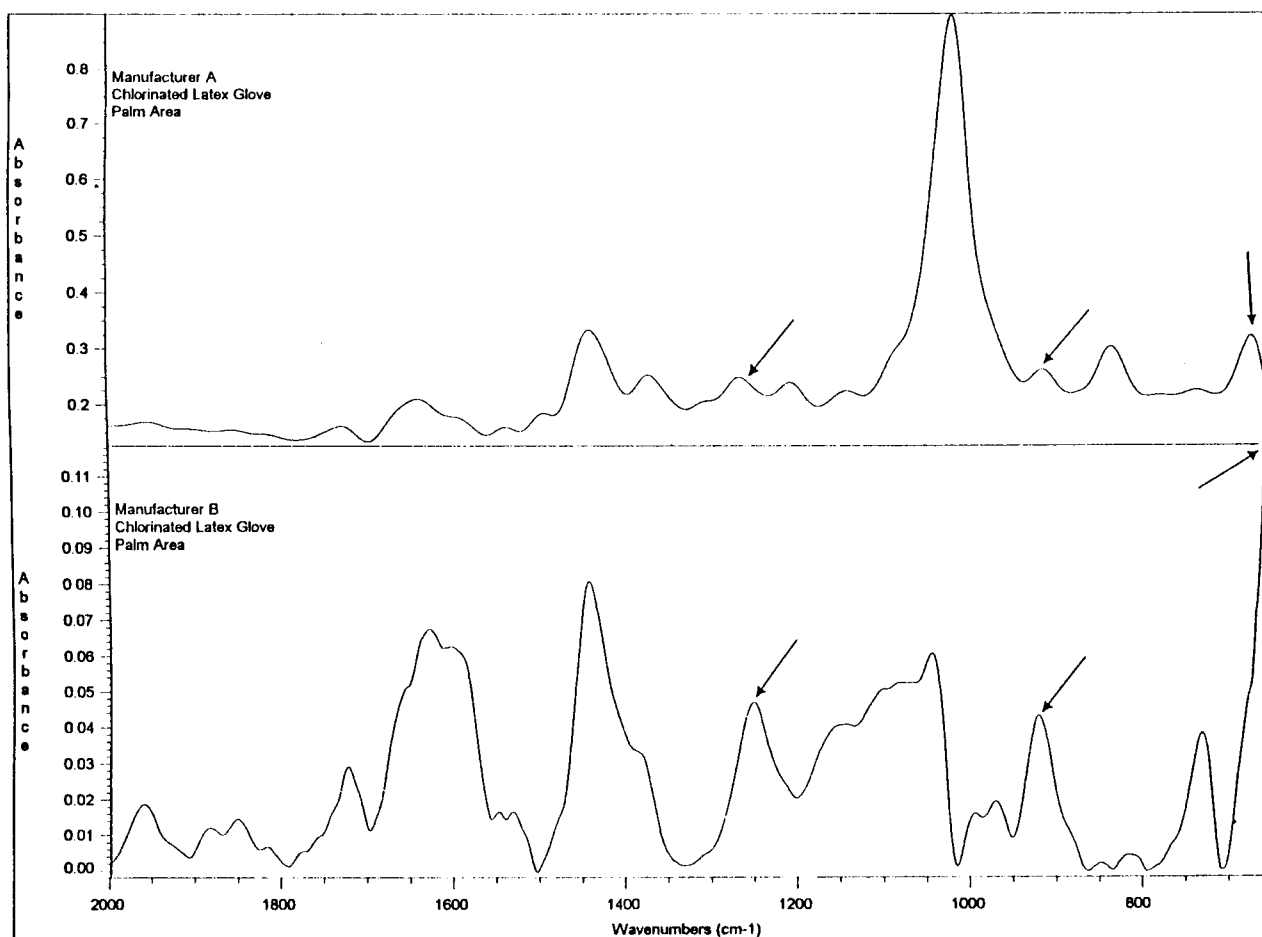
**Figure 2** ATR-FTIR spectra of the palm area (top) and the finger area (bottom) for the Manufacturer B chlorinated natural rubber latex glove.

under the absorbance peak from the C—H methyl band at  $1370\text{ cm}^{-1}$ .

By using this normalization procedure, a good estimate of chlorine content in these natural rubber latex glove samples can be obtained, factoring out the difference in absorbance attributed to thickness variations in samples. As shown in Figure 3, significant differences were exhibited at the following wavenumbers (range): 1260, 915, and  $670\text{--}650\text{ cm}^{-1}$ . Table I shows the peak heights obtained for the above three wavenumbers (range) of interest and that obtained for the C—H methyl band at  $1370\text{ cm}^{-1}$  for Manufacturer A and Manufacturer B latex glove samples obtained from the palm area. The peak height ratios at 1260, 915, and  $670\text{--}650\text{ cm}^{-1}$  are 0.96, 1.04, and 1.28 for the Manufacturer A glove sample, respectively, and are 2.00, 2.00, and 6.00, respectively, for the Manufacturer B glove sample. Hence, following spectral analyses and subsequent normal-

ization procedure, the chlorine content in the Manufacturer B chlorinated latex glove sample was found to be higher at these wavenumbers (range) than that in the Manufacturer A glove sample.

In addition, following close scrutiny of Figure 4, convincing differences between the chlorinated glove sample and the negative control samples were observed at the wavenumber ranges of 915 and  $670\text{--}650\text{ cm}^{-1}$ . Furthermore, Figures 1, 2, 3, and 4 reveal that the olefinic C—Cl stretch peak signature (functional group:  $\text{=C—Cl}$ ) assigned at  $915\text{ cm}^{-1}$  is in reality spread over the wavenumber range of  $930\text{--}915\text{ cm}^{-1}$ . This wavenumber range, instead of the single wavenumber, was used for spectral interpretations conducted for Figures 3 and 4. Table II shows the peak heights obtained for the above three wavenumbers (ranges) of interest and that obtained for the C—H methyl band at  $1370\text{ cm}^{-1}$  for a representative

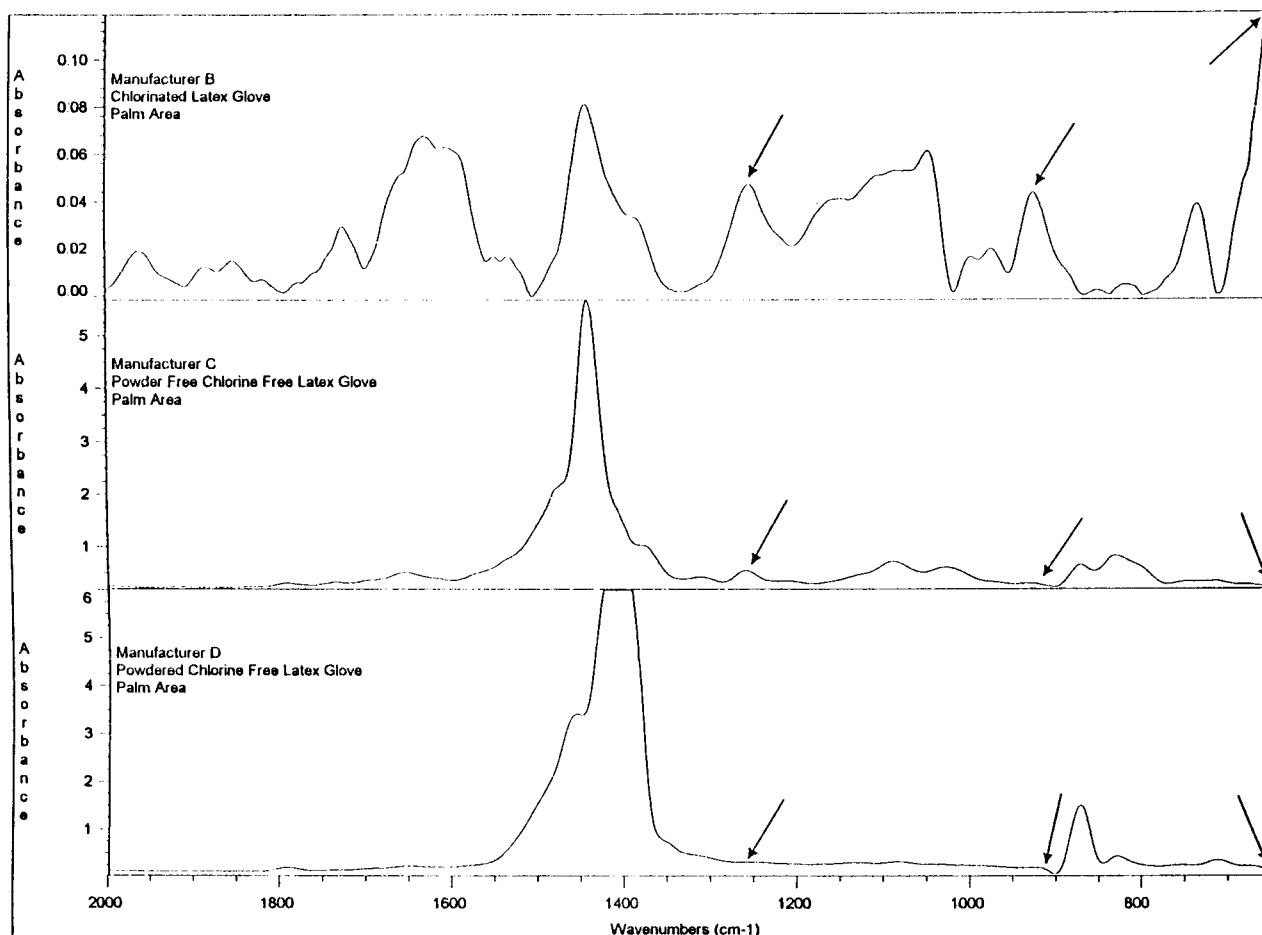


**Figure 3** ATR-FTIR spectra of palm areas of Manufacturer A (top) and Manufacturer B (bottom) chlorinated natural rubber latex gloves.

natural rubber glove sample from the palm area (Manufacturer B), for the powder-free chlorine-free natural rubber latex glove (Manufacturer C) from the palm area, and for the powdered chlorine-free natural rubber latex glove sample (Manufacturer D) obtained from the palm area. The peak height ratios at 1260, 930–915, and 670–650  $\text{cm}^{-1}$  are 2.00, 2.00, and 6.00 for the Manufacturer B glove sample, respectively. The peak height ratios for the chlorine-free glove samples are 0.57, 0.26, and 0.26, respectively, for the Manufacturer C glove sample, and 0.21, 0.11, and 0.15, respectively, for the Manufacturer D glove sample.

It was speculated from the peak height ratios calculated from the ATR-FTIR spectra of the negative control samples that the small but noticeable signature peaks at these wavenumbers (ranges), 1260, 930–915, and 670–650  $\text{cm}^{-1}$ , were primarily ascribed to the presence of some

chlorine-containing impurities in these samples. Following spectral interpretation and subsequent normalization procedure, the chlorine content in the Manufacturer B chlorinated latex glove sample was found to be much higher at these wavenumbers (ranges) than the chlorine contents in the chlorine-free natural rubber latex glove samples (Manufacturers C and D). Furthermore, on comparison between the peak height ratios calculated for the Manufacturer A glove sample (palm area) and those obtained for the chlorine-free glove samples (palm areas), it was also found that the chlorine content estimated in the Manufacturer A glove sample was also much higher than the chlorine contents obtained for the chlorine-free glove samples. The spectrum for the Manufacturer C powder-free chlorine-free latex glove in Figure 4 shows a distinct peak at 1260  $\text{cm}^{-1}$ . This is speculated to be the  $\text{CH}_3$  symmetric (umbrella) deformation from the silicone added in the latex



**Figure 4** ATR-FTIR spectra of palm areas of a representative (Manufacturer B) chlorinated latex glove (top), a powder-free chlorine-free (Manufacturer C) latex glove (middle), and a powdered chlorine-free (Manufacturer D) natural rubber latex glove (bottom).

emulsion to reduce the tackiness of this particular powder-free chlorine-free control glove. This observation leads to the exclusion of  $1260\text{ cm}^{-1}$  as a definitive absorption signature for the identification of chlorine in latex gloves.

Based on these above-noted observations, it is established that  $930\text{--}915$  and  $670\text{--}650\text{ cm}^{-1}$  are the two wavenumber ranges that are definitive and consistent absorption bands for the identification of chlorine in latex gloves. Both these ab-

**Table I** ATR-FTIR Spectral Analysis for the Two Chlorinated Natural Rubber Latex Glove Samples

Natural Rubber Latex Glove Sample Type	Peak Height for C—H Methyl Band at $1370\text{ cm}^{-1}$	Peak Heights at Following Wavenumber (Range) of Interest		
		$1260\text{ cm}^{-1}$	$915\text{ cm}^{-1}$	$670\text{--}650\text{ cm}^{-1}$
Manufacturer A (Palm Area)	0.25	0.24	0.26	0.32
Manufacturer B (Palm Area)	0.02	0.04	0.04	0.12



**Table II** ATR-FTIR Spectral Analysis for a Chlorinated Natural Rubber Latex Glove Sample (Manufacturer B), a Powder-Free Chlorine-Free Natural Rubber Latex Glove Sample (Manufacturer C), and a Powdered Chlorine-Free Natural Rubber Latex Glove Sample (Manufacturer D)

Natural Rubber Latex Glove Sample Type	Peak Height for C—H Methyl Band at 1370 cm <sup>-1</sup>	Peak Heights at Following Wavenumber (Range) of Interest		
		1260 cm <sup>-1</sup>	915 cm <sup>-1</sup>	670–650 cm <sup>-1</sup>
Manufacturer B (Palm Area)	0.02	0.04	0.04	0.12
Manufacturer C (Palm Area)	0.95	0.54	0.25	0.25
Manufacturer D (Palm Area)	1.44	0.30	0.16	0.21

sorption ranges should be used in combination for reliable identification of the presence of chlorine in glove samples when using ATR-FTIR spectrometry. The ATR-FTIR spectrum of the polychloroprene sample verified the strong signatures at these wavenumber ranges.

### Ion Chromatography

Along with the identification by ATR-FTIR spectroscopy, ion chromatography (IC) was also applied as a methodology for confirmation of the identification of chlorine in the latex gloves. Romberg's scheme was followed to determine semiquantitatively the chlorine content (wt %) in the latex gloves.<sup>4</sup> The combination of the two techniques would then establish a conclusive methodology for determining the chlorine content in commercial latex gloves.

For the Manufacturer C powder-free chlorine-free glove sample and for the Manufacturer D powdered chlorine-free glove sample both from the palm area, ion chromatograms show the absence of any significant chloride anion peak above background. However, in spite of careful flushing of the injection loop with the 18-M $\Omega$  reagent-grade water, it was found that there was a trace background peak for chloride ions in the injection blanks and in the negative control samples resulting from chlorine-containing impurities. Ion chromatograms for the palm area of the chlorinated latex gloves (Manufacturers A and B) were recorded. Figure 5 shows a representative ion chromatogram. The mean and the standard deviation values for the retention time and the area under the chloride anion peaks following triplicate runs for each of these two representative chlorinated glove samples are listed in Table III. Based on the

IC results, it is concluded that the Manufacturer B glove sample has a higher amount of chlorination than that of the Manufacturer A sample. The ATR-FTIR result is in qualitative agreement with this observation.

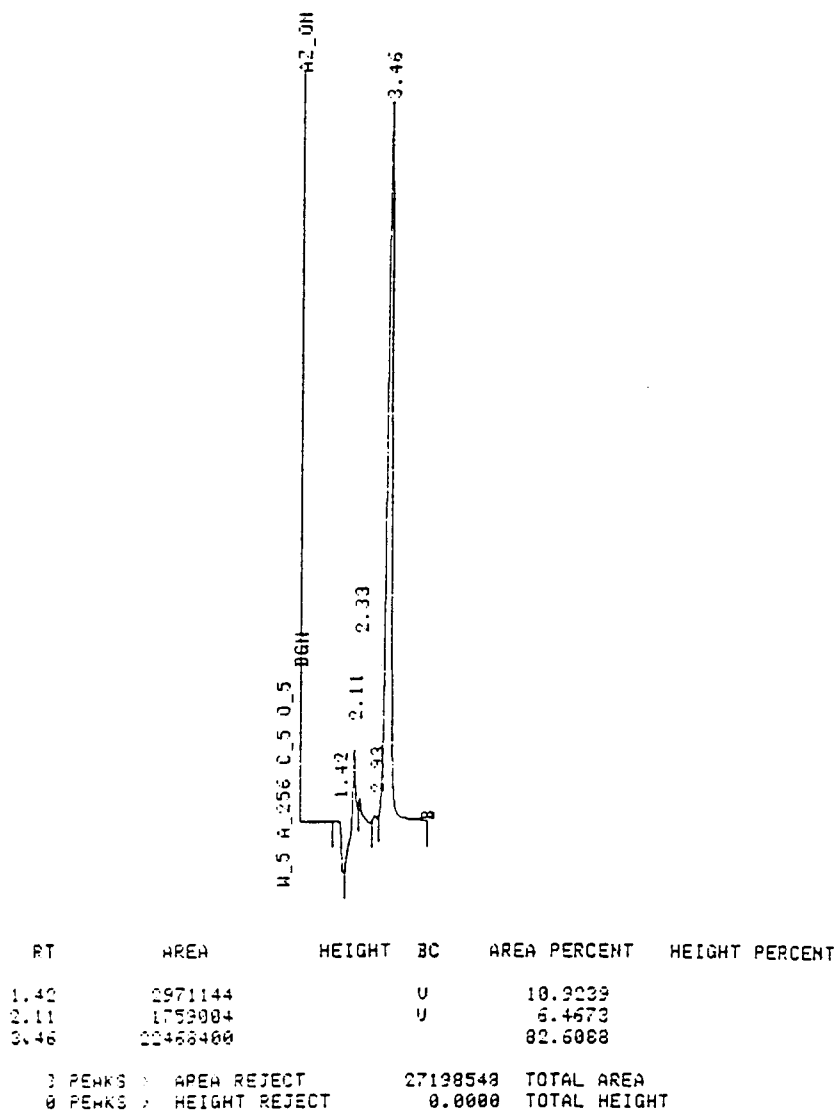
The empirical area-concentration relationship resulting from the calibration linearity test was used to quantify the amount of chloride ions present in the solution obtained for each of the chlorinated latex glove samples, as given by

$$\text{Area} = 3 \times 10^6 \times \text{concentration of chloride ions (in } \mu\text{g/ml)} \quad (1)$$

This is feasible because the same experimental parameters for the ion chromatography system were maintained for both the calibration test and the glove sample runs. The estimated concentration of chloride ions for a chlorinated latex glove sample was then converted to weight percentages as shown below:

$$\begin{aligned} &\text{Chlorine content (wt \%)} \\ &= \frac{\text{Concentration of chloride ions } (\mu\text{g/ml}) \times \text{solution volume (10 ml)}}{\text{Actual weight of latex glove sample used } (\mu\text{g})} \times 100 \end{aligned} \quad (2)$$

The calculated chloride ion concentrations and the chlorine content in weight percentages for the glove samples using the mean ( $N = 3$ ) area under the chloride anion peak are listed in Table III. As shown in Table III, the estimated chlorine content in the Manufacturer B glove sample is 0.5%,



**Figure 5** Ion chromatogram of the palm area of a Manufacturer A chlorinated natural rubber latex glove.

which is considerably higher than that estimated in the Manufacturer A glove sample (0.3%). This scheme can be applied for the estimation of chlo-

rine content in commercial natural rubber latex gloves with a statistically significant number of glove samples to investigate the glove-to-glove

**Table III** Ion Chromatographic Quantification of Mean Chlorine Content ( $N = 3$ ) in Chlorinated Natural Rubber Latex Glove Samples

Sample	Weight of Glove Sample (g)	Retention Time (min)	Area Under $\text{Cl}^-$ Peak	Concentration of $\text{Cl}^-$ Ions ( $\mu\text{g/ml}$ )	Chlorine Content (wt %)
Manufacturer A (Palm Area)	0.02963	$3.46 \pm 0.01$	$(2.25 \pm 0.01) \times 10^7$	7.5	0.3
Manufacturer B (Palm Area)	0.02956	$3.52 \pm 0.01$	$(4.77 \pm 0.01) \times 10^7$	15.9	0.5

variation in chlorine content as well to estimate variations between batches.

## CONCLUSIONS

The results from this study establish that the identification of chlorine in chlorinated natural rubber latex gloves can be performed by attenuated total reflectance (ATR)–Fourier transform infrared (FTIR) spectroscopy. ATR–FTIR studies revealed that to identify the presence of chlorine in a latex glove sample in a definitive and consistent manner, the sample should exhibit absorption band signatures at both the wavenumber ranges of 930–915 and 670–650  $\text{cm}^{-1}$ . Ion chromatography can be applied to confirm identification of chlorine in latex gloves and can be used for semiquantification of the chlorine content (wt %) in latex gloves. This methodology can be used by glove manufacturers to determine the amount of chlorine in batches of commercial gloves, and thereby prevent possible threats to public health arising from deterioration of surgical and examination chlorinated latex gloves under severe storage conditions before the end of their expected shelf life.

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