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Impermeability of Gloves and Differently Formulated NR Latex Films to ΦX174

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The permeability of gloves and differently formulated NR latex films to a challenge surrogate virus, ΦX174 of diameter 27 nm, was assessed by a newly-developed method which could detect holes greater than or equal to 2 μm. Samples from chlorinated and copolymerised natural rubber gloves and gloves with different extractable protein contents were found to be impermeable to the virus even when stretched 9× their original areas. Similar results were obtained with samples from nitrile and vinyl gloves. The integrities of the latex films were not affected when the films were of different high-ammoniated latex concentrate sources, different levels of non-rubber constituents, different curing systems, different moduli or different leaching protocols. The films maintained their barrier properties even after being aged at 70°C for 7 or 14 days. These clearly showed that stretched latex films were not porous. Furthermore, impermeability to a small virus such as ΦX174 indicated that the films could also be impervious to human viruses such as hepatitis B or C viruses, human immunodeficiency virus, herpes simplex virus and cytomegalovirus which are up to five times bigger than ΦX174.

Latex gloves are widely used as protective barriers against the transmission of infectious microorganisms. With the onset of Acquired Immune Deficiency Syndrome (AIDS), gloves are increasingly used to provide protection against human immunodeficiency virus (HIV), the causative agent of AIDS. Some studies showed that intact latex gloves are impenetrable by HIV[1] and another human pathogenic virus, herpes simplex virus type 1 (HSV-1)[2,3]. However, the occurrence of herpetic whitlow among three intensive care nurses who wore gloves[3] raised the question on the effectiveness of latex gloves as a barrier against virus.

A scanning electron microscopy study by Arnold *et al.*[4], claimed that gloves have pits 3 μm to 15 μm wide and channels 5 μm wide across the entire cross-section of the film. The observation of channels in the latex products has, however, not been repeated and has been strongly disputed based on the physical properties and the formation of latex films[5]. In fact scientists familiar with microscopic examination of latex rubber films attributed the purported observations to artifact[6].

It is generally agreed that the one litre water leak quality assurance test on gloves could not

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detect palm holes <20 μm and finger holes <40 μm[7] Virus found in the blood and other body fluids are much smaller than the holes detected by the water leak test The HSV-1, HIV and hepatitis B virus (HBV) are about 0 13. 0 10 and 0 04 μm in diameter, respectively[8] Using a surrogate virus, lambda phage[9] or ΦX174[10 11] of diameter 0 054 μm and 0 027 μm, respectively some gloves were found to allow virus passage These observations together with the report on the presence of pits and channels in latex films have prompted serious allegations that latex gloves are porous to viruses It was not known whether the virus leak was by penetration through defects such as pinholes and tears not detected by the water leak test or was by permeation through a porous film

It was the aim of this study to test the porosity (to viruses) of medical examination gloves and latex films prepared by certain formulations which could have an effect on the integrity of the films In a newly-developed test, the films were stretched 9-fold (to near maximum) and subjected to high titers of the challenge virus ΦX174

MATERIALS AND METHODS

Gloves

Portions of gloves from the palm or back were tested The gloves were commercially available gloves manufactured by different formulations and processes Examination gloves with different extractable protein levels, chlorinated gloves and copolymer gloves were manufactured in Malaysia from natural rubber latex, vinyl and nitrile gloves were of synthetic polymer

Preparation of Differently Formulated Latex Films

A number of latex films were prepared using formulations which could affect film properties A high ammoniated (HA) latex concentrate of 60% dry rubber content (d r c) was mixed/compounded at room temperature (RT) with sulphur vulcanising ingredients comprised of stabilisers (potassium hydroxide and potassium laurate), a crosslinking agent (sulphur), an accelerator [(zinc diethyl dithiocarbamate (ZDEC)], an activator (ZnO) and an antioxidant (Wingstay L® or antioxidant 2246) according to specified formulations (*Table 1*) The compounded latex was either prevulcanised or post-vulcanised In the post-vulcanisation process the compounded latex was matured at RT for 2 days before going through the film formation process A or B (*Figure 1*) In the pre-vulcanisation process the compounded latex was heated at 70°C for 2 h, cooled and stored at RT for 2 days before subjecting the latex to the film forming process A or B The film forming process A involved latex dipping wet gel leach, curing, post-dry leach, slurry dip and drying Process B incorporated all the steps except the post-dry leach

Ten different latex films (*Table 2*) were prepared from different latex concentrate sources, different levels of non-rubbers, different moduli, different curing systems and different leaching protocols as elaborated below

Films from different sources of HA latex concentrates Three latex films were prepared from three different sources of HA latex concentrates One film (*Sample 1, Table 2*) was made from HA latex concentrate prepared

TABLE 1. LATEX COMPOUNDING FORMULATIONS

Compounding formulations	I	II	III	IV
HA latex concentrate	100[a]	100[a]	100[a]	100[a]
Potassium hydroxide	0.30	0.30	0.30	0 30
Potassium laurate	0.30	0.30	0.30	0 30
Sulphur	0 50	1.00	2.00	2 50
Zinc diethyl dithiocarbamate	0.75	1.00	1.50	1.80
Zinc oxide	0 25	1.00	1.80	5 00
Antioxidants[b]	0 50	1 00	1 00	1 00

[a]Values in p.p.h r.

[b]Wingstay L®. 2,2-dicyclopentylene-bis-(4-methyl-6-t-butylphenol) — in *Formulation I*
Antioxidant 2246, 2,2-methylene-bis-(4-ethyl-6-t-butylphenol) — in *Formulations II, III* and *IV*

in the Rubber Research Institute's laboratory while the other two films (*Samples 2* and *3*) were made from HA latex concentrates produced by two Malaysian latex concentrate producers. The laboratory-prepared latex concentrate was produced by centrifuging a 0.2% ammonia preserved field latex of RRIM 600 at 7000 r.p.m by Alfa Laval Centrifugation. The centrifuge machine was adjusted to give a latex concentrate of 60% d.r.c. The concentrate was then ammoniated to 0 7% The two commercial latex concentrates were prepared in a similar manner except that the field latex was prepared from a number of clonal latices bulked together and preserved with other secondary preservatives such as tetramethyl thiuram disulphide (TMTD)-ZnO besides ammonia. Lauric acid (0.01%) was added to the HA latex concentrate. These latex concentrates were compounded with sulphur vulcanising ingredients according to *Formulation I*

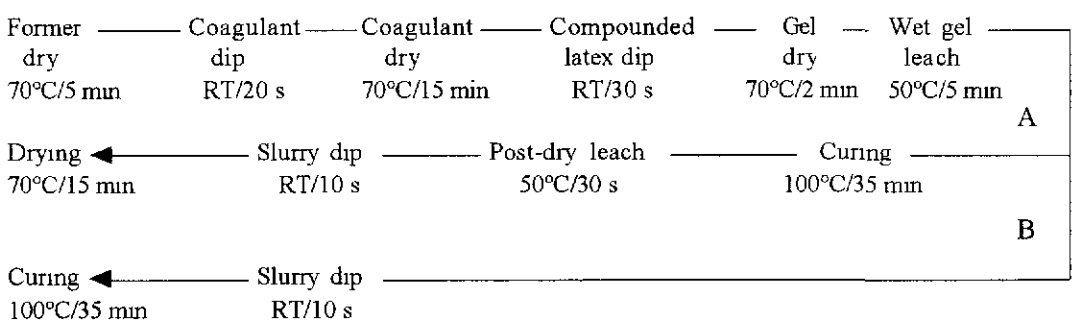

Figure 1. Latex film formation process, with (A) and without (B) post dry leach

TABLE 2 LATEX FILM PREPARATION

Sample number	HA latex source	Compounding formulation	Vulcanisation process	Film formation process
1	Laboratory-prepared	I	Post-vulcanisation	A
2	Commercial-I	I	Post-vulcanisation	A
3	Commercial-II	I	Post-vulcanisation	A
4	Unpurified RP[a]	I	Post-vulcanisation	A
5	Purified RP[a]	I	Post-vulcanisation	A
6	Commercial-II	II	Post-vulcanisation	A
7	Commercial-II	III	Post-vulcanisation	A
8	Commercial-II	IV	Post-vulcanisation	A
9	Commercial-II	I	Prevulcanisation	A
10	Commercial-II	I	Post-vulcanisation	B

[a]Prepared from commercial HA latex II

(*Table 1*), post-vulcanised and processed into films as outlined in *Step A* (*Figure 1*) The formulation and process of *Sample 3* served as the standard for comparison with samples produced by the following formulations and/or processes

Films with different levels of non-rubber constituents A sample of HA latex concentrate was ultracentrifuged on a Beckman Ultracentrifuge at 21 000 r p m for 45 min The latex separated into an upper fraction of rubber particles (RP) and a lower fraction of aqueous serum A portion of the RP was collected, redispersed in 0 2% ammonia and filtered through muslin cloth The resulting dispersion of unpurified RP was adjusted to 60% d r c and 0 7% ammonia Another portion of the RP was purified by dispersing it in 2% sodium dodecyl sulphate (SDS), filtered and ultracentrifuged again The purified RP were isolated, redispersed in 0 2% ammonia, filtered and adjusted to 60% d r c and 0 7% ammonia

The three latex samples the whole unfractionated HA latex concentrate, the unpurified RP and the purified RP, were compounded according to *Formulation I* (*Table 1*) and post-vulcanised through *Process A* (*Figure 1*) yielding *Samples 3,4* and *5*, respectively

Films of different modulus Three batches of the same HA latex concentrate were compounded according to *Formulations II, III* and *IV* (*Table 1*) which differ in the proportions of sulphur, ZDEC and ZnO to give *Samples 6,7* and *8*, a modulus at 700% extension (M700) of 9 7, 12 2 and 17 5 MPa, respectively The compounded latex was post-vulcanised following *Process A* (*Figure 1*)

Films of post-vulcanised versus *pre-vulcanised latex* A sample of HA latex concentrate was mixed with sulphur vulcanising ingredients at RT according to *Formulation I* (*Table 1*) A portion of the

compounded latex was post-vulcanised to give *Sample 3* while another portion was prevulcanised to give. *Sample 9* Both were processed through *Process A*

Films of different leaching process HA latex concentrate was compounded with sulphur vulcanising ingredients according to *Formulation I* and matured at RT for 2 days as in the post-vulcanisation step A portion of the matured latex was processed into *Sample 3 via Process A* which incorporates post-dry leach while another portion was processed to *Sample 10 via Process B* which eliminates the post-dry leach (*Figure 1*)

Ageing of Latex Gloves and Films

Latex gloves and films of different formulations were aged in an oven at 70°C for 7 days or 14 days

Test of Virus Porosity

Challenge virus The bacteriophage ΦX174 was chosen as a surrogate[8] for human pathogenic virus as it is a small virus of 27 nm diameter, non-pathogenic to humans, stable at different temperatures and pH levels and least adsorbing[12] The virus culture and bioassay utilising *Escherichia coli C* as the host were as previously reported[13] For experiments, the virus was suspended in a solution of 0 1% Tween-80® (v/v) in sterile deionised water Tween-80®, a surfactant, was used to lower the surface tension below that of water and to prevent any possible binding of the virus to the latex films

Compatibility of ΦX174 with extracts of gloves and films Although ΦX174 has been found to be stable when in contact with standard latex formulations used in commercial gloves[8], it was necessary to ascertain its compatibility with the formulations used in this study One gram of glove/latex film cut into small pieces was extracted with 5 ml of 0 1% Tween-80® at RT for 20 min The mixture was regularly vortexed After the specified period, 0 1 ml of the extract was mixed with an equal volume of ΦX174 — containing 1×10^3 plaque-forming units (pfu)/ml and incubated for 1 h at RT The reaction was stopped by adding 0 8 ml of LC Broth comprised of 10 g tryptone, 5 g yeast extract and 5 g sodium chloride in 1 litre of water The viable virus in the mixture was then bioassayed The fraction of surviving virus was determined by comparing the viable virus in the extracts with the viable virus in 0 1% Tween-80®

Permeation of ΦX174 through stretched latex film The ability of the challenge virus to pass through a piece of latex stretched over one end of a cylinder was determined in the following manner Fifty ml of ΦX174 ($5–19\times10^5$ pfu/ml) suspended in 0 1% Tween-80® was placed in a polycarbonate cylinder of 175 mm height and 56 mm inside diameter A piece of latex film with a drawn circle 18 mm in diameter was stretched over the open top of the cylinder such that the circle covered the mouth of the cylinder This stretched the film to 9-times the original area The latex film was fastened in place with a tight-fitting rubber band Parafilm was then wrapped around the fastened area to prevent leaks from the sides of the latex piece When the loaded cylinder was inverted, the virus suspension provided the challenge with a hydrostatic pressure of 20 mm water

The test consisted of three sequential phases In the first phase, the cylinder containing the

virus suspension was inverted onto a brown paper towel for 1 min to check for any gross, visual leak On passing the leak test, in the second phase the cylinder was inverted directly onto an agar plate containing top agar with the host bacterium *E coli C* for 2 min The agar plate was then incubated at 37°C for plaque formation In the third phase, the inverted cylinder was partially submerged in a 100 mm diameter petri dish containing 5 ml of 0 1% Tween-80® for 12 min Then 1 ml of the submersion solution exposed to the inverted cylinder was assayed for the virus in triplicate This assay could detect passage by challenge virus equivalent to 0 005 µl The agar contact approach (second phase) indicated qualitatively where the virus permeated or penetrated, but no quantitative information was obtained On the other hand, the submersion approach (third phase) allowed quantitation of virus passage, but no information on location of passage

The ability of this test procedure to detect holes was determined with 15 samples of latex condom with laser-drilled holes (*Table 3*) of photographically-documented diameters (Resonetics, Inc , Nashua, New Hampshire) These samples were not stretched In the paper contact phase (phase 1), all 5 holes of 15 5 µm to 29 6 µm diameter allowed fluid passage, while all 10 holes of 0 8 µm to 9 6 µm passed, indicating the cutoff hole size for this phase was between 9 6 µm and 15 5 µm For the agar contact phase (phase 2), all 7 holes of 9 1 µm and above allowed virus passage, while 6 holes between 1 4 µm and 2 5 µm gave mixed results One of the 3 holes in the 1 4 µm to 1 9 µm range allowed virus passage, and 2 of 3 holes in the 2 0 µm to 2 5 µm range allowed virus passage, indicating a cutoff hole size for this phase of about 2 µm The third phase was not done with the unstretched material, because the extended duration of that phase provided enough time for leakage at the folds in the latex samples under the rubber band seal There were no folds, hence no leaks when the samples were stretched

When the stretched latex films were punctured with sterile 120 µm diameter stainless steel acupuncture needles (Seirin Kasei Co , Ltd , Japan)(normally produces a 70 µm tear in unstretched films[14]), the first phase indicated no gross leak, the second phase showed plaques on the agar contact plate, and the third phase showed at least 5 µl of challenge suspensions had penetrated the tear Thus, although this 3-phase test was conducted at low pressure, it could detect open holes as small as 2 µm in unstretched films and tears made with a very thin needle in stretched films Since stretching the materials 9-fold in area would stretch a hole diameter 3-fold and produce a much thinner film (shorter path for virus to travel), it is expected that even smaller holes (perhaps less than 0 4 µm in unstretched material) should be detectable

RESULTS AND DISCUSSION

Compatibility of ΦX174 with Extracts of Gloves and Films

The compatibility of the challenge virus ΦX174, with the extracts of gloves and latex films was determined before testing the permeability of the latex products to the virus Results in *Tables 4* and *5* show that the virus was not significantly affected by contact with extracts of gloves and differently formulated latex films This demonstrated that none of the extracts were toxic to ΦX174

TABLE 3. WATER AND VIRUS PASSAGE THROUGH LASER DRILLED HOLES OF UNSTRETCHED PIECES OF CONDOM LATEX

Hole diameter (μm)	Water passage (phase I)	Virus passage (phase 2)
0.80	–	NT
1.40	–	–
1 70	–	+
1 90	–	–
2.15	–	–
2 25	–	+
2 50	–	+
4.80	–	+
9 10	–	+
9.60	–	+
15 50	+	+
16 30	+	+
16 70	+	+
27 80	+	+
29 60	+	+

–. No water/virus passage
+. Water/virus passage
NT: Not tested

Permeability of ΦX174 through Sections of Stretched Gloves

All sections of the NR gloves tested were effective barriers against passage of ΦX174 (*Table 4*). None showed any porosity to virus passage even when the films were stretched 9× their original area. These results were consistently obtained from examination gloves with extractable protein values ranging from 0.2 mg/g to 1.4 mg/g glove, from chlorinated gloves and from copolymer gloves. The two synthetic gloves, vinyl and nitrile, tested also exhibited good barrier properties against ΦX174 (*Table 4*). However, while nitrile gloves could be stretched to 9× their original area, vinyl gloves could be stretched only 2× Furthermore, it was observed that the stretched nitrile gloves easily tore on being punctured by an acupuncture needle. This did not happen with the natural latex gloves.

Permeability of ΦX174 through Stretched Latex Films of Different Formulations

Films from different source of HA latex concentrate. The composition of HA latex concentrates, the starting material for most dipped goods, may vary depending on the source of the latex. The variations could stem

TABLE 4 COMPATIBILITY OF ΦX174 WITH EXTRACTS OF DIFFERENT GLOVES AND THE PERMEABILITY OF PORTIONS OF THE GLOVES TO THE VIRUS

Gloves	Virus surviving fraction[a]	Virus permeated	
		Direct contact	In buffer (μl)
Examination-I	0 94 ± 0.5	NP[b]	<0.005
Examination-II	1.06 ± 0.24	NP	<0.005
Chlorinated	1.00 ± 0 11	NP	<0.005
Copolymer	1 14 ± 0.06	NP	<0.005
Vinyl	1.08 ± 0.04	NP	<0.005
Nitrile	0 90 ± 0.00	NP	<0.005

Examination gloves I EP of 0.2–0 3 mg/g glove
Examination gloves II. EP of 1.0–1.4 mg/g glove
[a]Relative to virus in 0 1% Tween-80® Data represents the mean (± standard error) of results from two experiments
[b]NP No plaque formed

from the clones used to bulk the latex, the age of the latex and the additives added to the field latex and latex concentrates. Normally, TMTD-ZnO is added to field latex as a secondary preservative besides ammonia, and lauric acid is added to HA latex concentrate to boost its mechanical stability. All these differences however, were found not to affect the barrier property of the latex films (*Table 5*). Films from the laboratory-prepared latex concentrate of monoclonal RRIM 600 without any secondary preservative and lauric acid (*Sample 1*) showed similar performance as films from commercially prepared latex concentrates where a number of clones were mixed and other additives added (*Samples 2* and *3*). All were impermeable to ΦX174.

Films of different levels of non-rubber constituents. HA latex concentrate is normally comprised of 60% rubber particles dispersed in aqueous serum containing about 1.6% of non-rubber substances such as proteins, carbohydrates, fatty acid soaps and salts[15]. Dipped film from this latex will have RP interspersed with a layer of non-rubber substances. Stretching this film (*Sample 3, Table 5*) to 9× its original area did not allow any virus to go through. Similar results were obtained with films of unpurified RP (*Sample 4*) or films of purified RP (*Sample 5*) where the membrane components (lipids and proteins) were replaced by SDS. These results indicated that the non-rubber substances surrounding the membrane of the RP or constituting the interstitial layer between the RP did not influence the integrity of the latex film against the permeation of virus.

Films of different modulus Compounding the latex with different ratios of S:ZDEC:ZnO resulted in vulcanised films of different modulus values. The higher the modulus the higher will be the crosslinking between the

TABLE 5 COMPATIBILITY OF ΦX174 WITH EXTRACTS OF DIFFERENTLY FORMULATED LATEX FILMS AND THE PERMEABILITY OF THE FILMS TO THE VIRUS

Sample number	Latex films	Virus surviving fraction[a]	Virus permeated	
			Direct contact	In buffer (μl)
1	RRIM 600 HA	1.08	NP[b]	<0 005
2	Commercial HA-I	1 18	NP	<0 005
3	Commercial HA-II	0.99 ± 0 11	NP	<0.005
4	Unpurified RP	0.93 ± 0 01	NP	<0.005
5	Purified RP	0.85 ± 0 10	NP	<0 005
6	Modulus-9.7 MPa	0 86 ± 0 11	NP	<0.005
7	Modulus-12.2 MPa	1 01 ± 0 15	NP	<0.005
8	Modulus-17 5 MPa	0 82 ± 0 11	NP	<0 005
9	Prevulcanised	0 94 ± 0 04	NP	<0 005
10	Process B	0 93 ± 0 17	NP	<0 005

[a]Relative to virus in 0 1% Tween-80® Data represents the mean (± standard error) of results from two experiments except for *Samples 1* and *2* which represent the results of single experiments
[b]NP. No plaque formed

rubber chains. *Table 5* shows that the modulus had no effect on the integrity of the latex films. All three samples (6, 7 and 8) of M700 values 9.7, 12.2 and 17.5 MPa, respectively, prevented passage of ΦX174. In fact the films made from unpurified and purified RP (*Samples 4* and *5*) with much lower moduli of 3.8 MPa and 5.6 MPa, respectively, exhibited similar good barrier properties.

Films of post-vulcanised versus *pre-vulcanised latex* In the process of producing dipped goods the HA latex concentrate has to be compounded with a number of sulphur vulcanising ingredients (*Table 1*). Large-scale manu-facturers usually have the facilities to prepare their own dispersions and thus have their own formulated latex whereas the small-scale manufacturers have limitations on this. Thus, post-vulcanisation is the preferred process by the former group of manufacturers while the latter group rely on the prevulcanised latex available on the market.

In both cases it could be seen that the films (*Samples 3* and *9* of *Table 5*) gave equally effective protection against the penetration of ΦX174.

Effect of post-dry leaching process. With the advent of the latex protein allergy issue, more glove manufacturers are adopting the extra post-dry leach process to reduce the extractable protein content to <1 mg/g glove. The previous process did not incorporate this and normally results in gloves having extractable protein content higher than 1 mg/g glove. *Table 5* shows that the extra leaching step did not produce any adverse effect on the barrier integrity of the latex film (*Sample 3*)

when compared to film prepared without the post-dry leach (*Sample 10*) The film maintained its property of preventing any virus passage

Effect of Ageing

Ageing is known to reduce the tensile strength and elongation at break of latex film Ageing, however, did not affect the barrier properties of these films Chlorinated gloves and films prepared from purified RP and HA latex concentrate retained their barrier properties even after being aged for 7 days or 14 days at 70°C (*Table 6*)

By the criteria of this 3-phase test, all the latex films representing a range of formulations and processes were effective barriers to transmission of a small virus, ΦX174 None of the samples displayed evidence of holes as large as 2 μm Furthermore, no permeation through quite thin, stretched samples was observed with this very sensitive test This is interpreted to mean that there are few, if any, pores or holes through unstretched latex films large enough to allow virus passage This is consistent with previous findings that latex condoms are effective barriers over longer test periods at much higher pressures[16] and that intact latex gloves are also effective barriers[10] It is also consistent with the recent demonstration that *ASTM F1671-95*[17] could detect laser-drilled holes in condom latex down to about 1 μm, but no virus passage was detectable in control samples with no intentional defects Similarly, latex condoms tested over 24 h allowed no virus passage by permeation and diffusion[18] Thus, this combined evidence indicates that the large holes reported by Arnold, *et al.*[4], are not common to laboratory-prepared latex samples nor to marketed latex condoms or gloves. but must be considered as occasional defects subject to effective quality control procedures

This inherent latex film quality could be partly explained by the chemistry of latex film formation In the formation of dipped film, the negatively-charged compounded unvulcanised RP or prevulcanised RP are attracted to positively-charged former, coated with 10% calcium nitrate This results in deposition of the RP on the former, inducing layers of RP to coalesce over one another As 80%–90% of the RP from HA latex concentrates have diameters of <1 μm (50%–80%. <0 5 μm)[19]. a narrow cross-section of a finished latex film of 80 μm thickness will contain at least 80 closely-packed RP In such a scenario. one could expect that it is unlikely that a virus can permeate through the whole cross-section of the film in any reasonable amount of time Furthermore, the stacking of the RP of varied diameters might occur at random, not aligned over one another This possibly explains the virus impermeability through films with or without the interstitial layer between the RP, such as in the whole latex concentrate film and in the unpurified and purified RP films, respectively The interstitial layer between well-aligned RP could offer a weak spot in the film

As porosity is not an issue, the reports of virus penetration through gloves could result from manufacturing defects or defects created during use Korniewicz, *et al* [20], demonstrated that 24% of latex examination gloves used in two high-risk units, a surgical intensive care unit and AIDS unit, had leaks The leaks depended on the brands of gloves, clinical use levels and duration of use In another study. the incidence of leaks were found more with

TABLE 6 PERMEABILITY OF LATEX FILMS AND GLOVES AGED AT 70°C TO ΦX174

Films/Gloves	Days aged	Virus permeated	
		Direct contact	In buffer (μl)
Purified RP film	7	NP[a]	<0 005
	14	NP	<0 005
HA latex film	7	NP	<0 005
	14	NP	<0 005
Chlorinated glove	7	NP	<0 005
	14	NP	<0 005

[a]NP No plaque formed

used vinyl (85 3%) than with used latex (18 4%) gloves[21] These studies reflect the need to determine the factors that affect the performance of gloves in use, so that the quality of NR gloves can be improved further

CONCLUSION

All NR latex films tested with the new method which could detect holes greater than or equal to 2 μm, were found to be effectively impermeable to surrogate virus, ΦX174, 27 nm in diameter This was irrespective of the variations in the composition of the latex concentrate used, the levels of non-rubber constituents surrounding the RP, the modulus values, the vulcanising systems and the leaching protocols The impermeability to the virus was also observed in NR gloves with extractable protein values ranging from 0 2 to 1 4 mg/g glove, chlorinated gloves and copolymer gloves Ageing at 70°C for 7 days or 14 days seemed not to affect the barrier property of the latex films Although vinyl and nitrile gloves showed similar barrier properties as the NR latex gloves, vinyl gloves differed in being only able to stretch to 2× the original area and nitrile gloves easily tore on puncturing

Impermeability to ΦX174 implied that the latex films were also impermeable to human viruses which are up to five times bigger So the reported leaks in gloves could be due to defects in manufacturing or defects created during use but not due to inherent porosity of the gloves

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