Hydrofluoric acid (HF): hazards, review of case reports, objective comparison of different washing solutions. Presentation of two new models for eye (EVEIT® and OCT) and human skin (BIO-EC) decontamination.

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Introduction

HF is widely used in different industries but is a very hazardous chemical because of the acid corrosivity of its hydrogen ion (H^+) and the chelating properties against calcium and magnesium of its fluoride ion (F^-). HF induces both tissues necrosis and cardiac systemic toxicity (depending on its concentration and on the surface of contamination).

Objectives

To compare the efficacy of water and/or Calcium Gluconate (CaG) *versus* Hexafluorine® (an available chelating and hyperosmolar specific solution for HF decontamination) on skin and eyes.
To correlate *in vitro, in vivo* and clinical results.

Method

Method 1 - Clinical case reports

Case reports show that the protocols usually recommended in order to decontaminate HF splashes in the workplace with tap water and CaG have not always prevented deep burns and sequelae. Washing with Hexafluorine® involves immediate pain relief, prevents development of serious burns leaving no sequelae and minimizes both secondary care and loss of work time. 32 cases in industrial settings exposed to different concentration (diluted or concentrated) HF have been published.

5 case studies of emergency decontamination with Hexafluorine®(1)

Number of cases	Splashed by	Affected body surface	Type of washing	Consequences/Results
1	HF/HCl bath	Total immersion	Hexafluorine® on the body,	Slight burns on the abdomen and the back
			Ocular washing with water	Serious burn on the left eye
1	70% HF vapour	Right cheek	Hexafluorine®	Slight painless erythema . Application the next day with calcium gluconate gel, no lost work time
1	38% HF	One eye	Hexafluorine®	No burns, no lost work time
2	5% HF	Body	Hexafluorine®	No burns, no lost work time

SERIES OF 16 CASES AT OUTOKUMPU (AVESTA, various sites, Sweden) (23) Decontamination with Hexafluorine®

Number of Cases	Splashed with	Affected body surface	Duration of contact	Work loss
2	70% HF	Left forearm– oral cavity	< 1 min	0 - 1
1	HF (concentration unknown)	One eye	< 1 min	0
2	HF/HNO_3 pH=1	One eye	< 1 min	0 - 0
1	HF/HNO_3 pH=1*	One eye	3 - 5 min	3
1	HF/HNO_3 pH=1	Two eyes	< 1 min	0
1	HF/HNO_3 pH=1	One thigh	< 1 min	0
2	HF/HNO_3 pH=1	Two thighs	1h - 1h30	2 - 2
1	HF/HNO_3 pH=1*	Face	3 - 5 min	3
2	HF/HNO_3 pH=1	Face + oral cavity – Forehead	< 1 min	1 - 1
3	HF/HNO_3 pH=1	Forearm– arm + hand – Two elbows	< 1 min	0 – 0 - 1
1	HF/HNO_3 pH=1	Wrists	2 h	0
RESULTS	Immediate analgesic effect, no sequelae. In 75% of cases including two splashes with 70% HF, no additional care was required and the average lost work time was less than 1 day (σ = 1.1)			

HF/HNO_3 mixture: HF 6% and HNO_3 15%
**preparation including sulphuric acid (H_2SO_4) with an unknown concentration*

SERIES OF 11 CASES AT THE MANNESMANN PLANT (Remscheid, Germany)

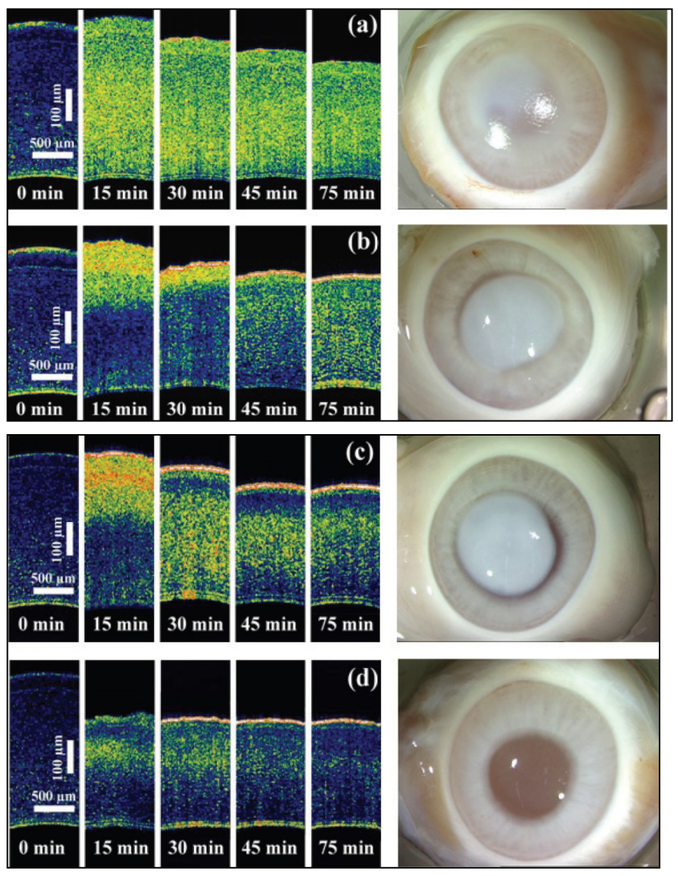
Splash	40% HF	6% HF /15% HNO_3	40%HF	6% HF / HNO_3 15%
Number of cases	1	1	5	5
% Affected area	1 eye*	1 eye	0.2 – 1 – 4.5 – 4.5 – 16.5*	0.2 – 2.25 – 4 - 4.5 - 10.5
First washing (on the site of the accident)	Hexafluorine®	Hexafluorine®	Hexafluorine®	Hexafluorine®
Second washing (at the infirmary)	Hexafluorine®	Hexafluorine®	Hexafluorine®	Hexafluorine®
RESULTS	No sequelae, no further care required no lost work time			

** ocular and cutaneous splash with 40% HF*

Among these cases, 5 accidents could have presented lethal risks but no sign of systemic effects has been observed when decontamination with Hexafluorine® was performed immediately and CaG treatment by applied, when required.

Method 2.1 - New *ex vivo* models for eye contamination:

Acute Ex Vivo Eye Irritation Test (aEVEIT) and Optical Coherence Tomography (OCT) technique for eye burn. EVEIT, associated with OCT high speed micrometer resolution, offers the possibility to qualify and quantify the penetration into the eye of 25 µL of 2.5 % HF on a filter paper in contact with enucleated rabbit eye. Decontamination occurs just after 20 s of contact. The comparison is done between 15 min of tap water rinsing, the use of 1 % CaG solution and Hexafluorine® washing during 3 minutes (166 mL/min).



Eye burnt with 2,5 % HF: OCT and morphological appearance

a) Without rinsing = burn

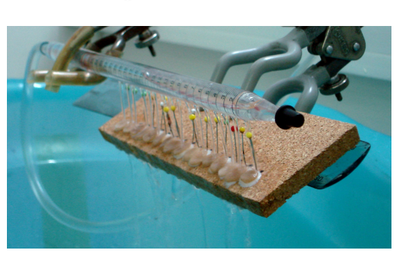
b) Water rinsing = burn

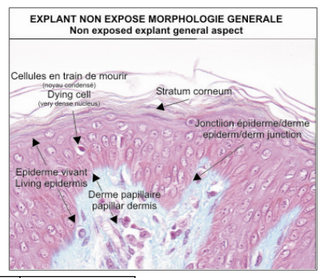
c) 1 % Calcium Gluconate rinsing = burn

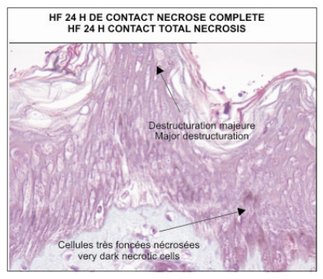
d) Hexafluorine® rinsing = preserved cornea

Method 2.2 – New ex vivo model for skin HF contamination:

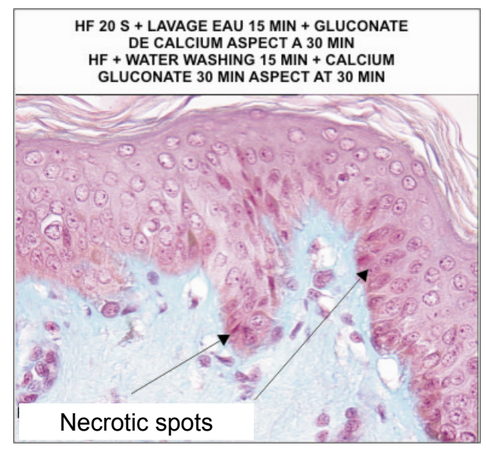
BIO-EC technique using human skin explants burnt by topic application of 30 µL 70 % HF on a filter paper for 20 s. Histological samplings are made at 20 s, 5, 10, 15, 30 min, 1, 2, 4 and 24 hours. 40X optical microscopy shows 4 skin layers: stratum corneum, basal epidermis, papillary and reticular dermis. It precisely shows the progressive penetration and the extension of cellular lesions within tissue. Then this study compares the efficacy of water rinsing during 15 min followed by a Ca-G application versus washing with Hexafluorine®.

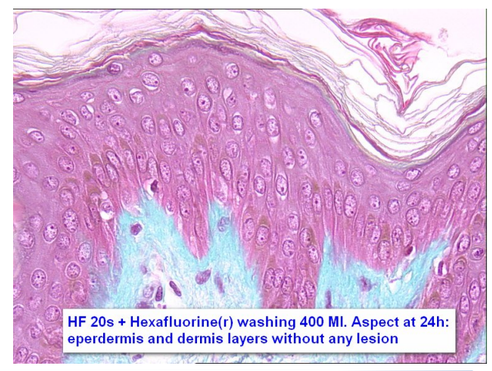






		Control (untreated group) (20 explants)	HF without washing (18 explants)	HF + water washing + calcium gluconate (16 explants)	HF + Hexafluorine 400 ml (16 explants)
T0	Epidermis	GM = good morphology			
	Papillary dermis	GM			
	Reticular dermis	GM			
20 s	Epidermis	GM			
	Papillary dermis	GM			
	Reticular dermis	GM			
5 min	Epidermis	GM	PN + AC	GM	GM
	Papillary dermis	GM	PN + AC	GM	GM
	Reticular dermis	GM	PN + AC	GM	GM
10 min	Epidermis	GM	PN = pyknotic nuclei	GM	GM
	Papillary dermis	GM	AC = Acidophilic cytoplasm	GM	GM
	Reticular dermis	GM	PN + AC	GM	GM
15 min	Epidermis	GM	PN + AC	NP + CA moderately	GM
	Papillary dermis	GM	PN + AC	PN + AC	GM
	Reticular dermis	GM	PN + AC	PN + AC	GM
30 min	Epidermis	GM	PN + AC	Some necrotic cells	GM
	Papillary dermis	GM	PN + AC	GM	GM
	Reticular dermis	GM	PN + AC	GM	GM
1 h	Epidermis	GM	PN + AC	GM	GM
	Papillary dermis	GM	PN + AC	GM	GM
	Reticular dermis	GM	PN + AC	GM	GM
2 h	Epidermis	GM	PN + AC	GM	GM
	Papillary dermis	GM	PN + AC	GM	GM
	Reticular dermis	GM	PN + AC	GM	GM
4 h	Epidermis	GM	PN + AC	Slightly edematous cells with mild acantholysis	GM
	Papillary dermis	GM	PN + AC	GM	GM
	Reticular dermis	GM	PN + AC	GM	GM
24 h	Epidermis	GM	Totally necrotic	Very edematous cells with a very clear cytoplasm	GM
	Papillary dermis	GM	PN + AC	PN + AC	GM
	Reticular dermis	GM	PN + AC	Lesser alterations	GM





Results

For eye burns, 2.5 % HF needs only 240 s to achieve full corneal penetration. Decontamination with water and/or with calcium gluconate has resulted in deep stromal changes: loss of transparency with milky aspect, very characteristic of the burn by HF. Use of CaG initially stopped the burn but a later progression. Hexafluorine® anti-HF rinsing solution has proved to fully stop burns due to its specific properties. This is the only rinsing solution that keeps the cornea totally clear 75 min after burning.
For skin burns, 70 % HF on skin without rinsing induces the first cellular lesions after 1 minute of contact. HF reaches the deepest layer of dermis in less than 5 minutes. The BIO-EC technique is able to compare the evolution of a human skin spontaneously burnt with 70 % HF, after water rinsing and calcium gluconate application and after decontamination with a 2 x 200 mL Hexafluorine® spray. Rinsing 15 min with water followed by a unique Ca-G application only delays the initial corrosive effect but the process goes on after 4 h and up to 24 h. With Hexafluorine®, we observe a total absence of lesion in any layer and at any time: precociously or later up to 24 h.

Discussion

Experimental results obtained with *ex vivo* models are in concordance with published clinical results. Washing with water allows superficial decontamination and CaG only temporarily helps to bind toxic fluoride ions. But complete decontamination can only be achieved with Hexafluorine® which shows a good ability to prevent or minimize HF burn lesions and to prevent systemic effects.

Conclusion

The double hazardous mechanisms and the lethal risk of HF require highly efficient emergency care in case of contact. Based on the results obtained here, Hexafluorine®, as a specific rinsing solution, is fully effective on ocular as well as cutaneous HF splash decontamination. In the future, the use of these two new *ex vivo* models on eye and skin could help us to evaluate the chemical contamination due to various chemicals and the benefit of using improved decontamination agents.