

pH Stability of ophthalmic solutions

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Background: In this study, we evaluated the pH value of 17 ophthalmic solutions, and we investigated whether the pH of these solutions changed over time after the bottle was opened.

Methods: Fifteen bottles of each type of solution were chosen at random from different production lots. A 0.05-ml increment was taken from each bottle and was measured daily using a microPH 2002 Crison pH-meter over a period of 30 days.

Results: The results revealed differences between the pH values of the solutions; nine solutions presented pH values within ocular comfort range and eight solutions presented pH values between 3.5 and 6.4. Ten solutions presented nonstatistically significant variations over time ($p > 0.01$) and seven solutions presented isolated but statistically significant variations.

Conclusions: We may assume that the nine solutions with pH values within the ocular comfort range will not produce initial discomfort. The solutions with acid pH values will produce initial discomfort. The solutions with nonstatistically significant pH variations over 30 days in relation to their initial pH values presented great stability.

Key Words: Aqueous solution, cornea, eyedrops, ophthalmic solutions, pH variation, topical dosage

Except for the skin, the eye is the most easily accessible site for topical administration of medication. The most commonly used dosage form is an aqueous solution of a drug delivered as an eyedrop, which is applied topically to act on the ocular surface or in the interior of the eye.

An aqueous solution instilled onto the eye is subject to the influences exerted by the normal protective physiological mechanisms present in the eye. Assuming normal tear drainage, the instilled solution is eliminated completely from the eye within 5 or 6 minutes of its application. This results in a very short period during which the drug has access to the ocular tissues.

The cornea is relatively impermeable to most drugs due to its trilaminar structure, which consists of a hydrophilic stroma located between the outermost highly lipophilic epithelial layer and the endothelial layer, which is less lipophilic. The intact corneal epithelium contributes to the resistance to hydrophilic drugs, whereas the stroma limits permeability to lipophilic drugs. Although a damaged epithelium does not offer great resistance to the permeability of hydrophilic drugs, in the case of a healthy corneal epithelium, the permeability to hydrophilic drugs is achieved by varying the physicochemical properties of the drug, either by derivation chemistry or by altering the pH and so manipulating its ionization.¹ In spite of the fact that the corneal epithelium is relatively impermeable to most ocular drugs, transcorneal penetration is believed to be the best pathway for drug absorption into the eye.¹⁻³

The paracellular and transcellular pathways are the two mechanisms for drug transport across the cornea. In the paracellular mechanism, the drug penetrates through inter-

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Table 1. Ophthalmic solutions evaluated, their trade names, manufacturing laboratory, composition and action, remarks

Name (manufacturer/ country of manufacture): indication for use/remarks	Active ingredients (each ml)	Inactive ingredients (excipients)	Action
Oftalmotrim Dexta® (Cusi S.A./Spain): anti-inflammatory; protect from light, discard a month after opening bottle	1 mg dexamethasone sodium phosphate; 1 mg trimethoprim 10,000 IU polymyxin B sulphate	Benzalkonium chloride, sulfuric acid, C1Na, sodium hydroxide, trisodium citrate, polysorbate 80, citric acid, water for injection	Association of corticosteroid (dexamethasone) and antimicrobial agents (trimethoprim and polymyxin B). Reduces the inflammation and eliminates the infection
Cortofal® (Cusi S.A./ Spain): anti-inflammatory; protect from light, discard a month after opening bottle	1 mg clobetasone butyrate	Benzalkonium chloride, C1Na, monosodium phosphate, edetate disodium, polysorbate 80, hipromellose, water for injection	Anti-inflammatory steroid
Oftalar® (Cusi S.A./ Spain): anti-inflammatory; protect from light, discard at end of treatment; discard a month after opening bottle	1 mg pranoprophren (DCI)	Benzalkonium chloride, boric acid, polysorbate 80, sodium tetraborate, edetate sodium, water for injection	Nonsteroidal anti-inflammatory
Poly-Pred Liquifilm® (Allergan/Ireland): anti-inflammatory; discard at end of treatment	5 mg/ml prednisolone acetate 5 mg/ml neomycin sulfate 10,000 µ/ml polymyxin sulfate B	14 mg/ml Liquifilm (polyvinyl alcohol), polysorbate 80, propylene glycol, sodium acetate, thimerosal, water for injection	Anti-inflammatory steroid and antibiotic
Colircusi Gentamicina® (Cusi S.A./Spain): ocular infections; discard a month after opening bottle	3 mg gentamicin (sulfate)	Benzalkonium chloride, monosodium phosphate, disodium phosphate, C1Na, water for injection	Antibiotic of the aminoglycoside group
Oftalmotrim Colirio® (Cusi S.A./Spain): ocular infections; protect from light, discard a month after opening bottle	1 mg trimethoprim 10,000 IU polymyxin sulfate B	Methylhydroxybenzoate sodium, sulfuric acid, C1Na, water for injection	Antimicrobial agents association
Alomide® (Alcon Iberhis S.A./Belgium): allergic ocular disorders; discard a month after opening bottle	Lodoxamide (DCI) 1 mg/ml tromethamine	Benzalkonium chloride, 0.007 mg/ml mannitol, hydroxypropyl methylcellulose, sodium citrate, citric acid, edetate disodium, tyloxapol, sodium hydroxide, and/or hydro-chloric acid, purified water	Antihistaminic and anti-inflammatory activity
Colircusi Ciclopléjico® (Cusi S.A./Spain): mydriatic and cycloplegic action; discard a month after opening bottle	10 mg cyclopentolate hydrochloride	Methyl parahydroxybenzoate, propyl parahydroxybenzoate, C1Na, water for injection	Parasympathetic action with mydriatic and cycloplegic action
Colircusi Atropina® (4:1) (Cusi S.A./Spain): mydriatic and cycloplegic action; discard a month after opening bottle	5 mg atropine sulfate	Parahydroxybenzoate of methyl, parahydroxybenzoate of propyl, C1Na, disodium phosphate, monopotassium phosphate, water for injection	Parasympathetic action with mydriatic and cycloplegic action

cellular space; in the transcellular mechanism, the drug penetrates through the intracellular space. The principal drug properties that influence drug absorption via the transcellular pathway are the lipophilicity, the pKa, which determines the percentage of the absorbed un-ionized form of the drug present at a given pH, the solubility, and the molecular size.⁴⁻⁸

The adjustment of an ophthalmic solution's pH by the appropriate choice of a buffer is one of the most important considerations in its formulation. Buffers may be used in ophthalmic solutions for one or more of the following reasons: to maintain the physiological pH of tears upon administration in order to minimize epiphora and patient discomfort; to optimize the therapeutic activity of the

Table 2. Ophthalmic solutions evaluated, their trade names, manufacturing laboratory, composition and action, remarks

Name (manufacturer/ country of manufacture): indication for use/remarks	Active ingredients (each ml)	Inactive ingredients (excipients)	Action
Colircusi Anestésico® (4:1) (Cusi S.A./Spain): local anesthetics: discard a month after opening bottle	5 mg tetracaine hydrochloride 0.5 mg naphazoline hydrochloride	Chlorobutanol, monosodium phosphate, disodium phosphate, CNa, water for injection	High anesthetic action
Cusimolol® (4:1) (Cusi S.A./Spain): reduces intraocular pressure: protect from light	5 mg timolol (maleate)	Benzalkonium chloride, monosodium phosphate, disodium phosphate, CNa, water for injection	Reduces the intraocular pressure, beta-adrenergic blocking agent
Xalatan® (Pharmacia& Upihñ/Sweden): reduces intraocular pressure: protect from light, discard a month after opening bottle	50 micrograms Latanoprost	Benzalkonium chloride, CNa, disodium hydrogen phosphate anhydrous, water for injection	Reduces intraocular pressure in acute glaucoma
Elebloc® (Cusi S.A./Spain): reduces intraocular pressure: discard at end of treatment, discard a month after opening bottle	20 mg arteolol hydrochloride	Benzalkonium chloride, CNa, monobasic sodium phosphate, dibasic sodium phosphate, water for injection	Reduces intraocular pressure, nonselective beta-adrenoceptor blocking agent
Colircusi Philocarpina® 2 (Cusi S.A./Spain): reduces intraocular pressure: discard a month after opening bottle	20 mg pilocarpine chloride	Benzalkonium chloride, polividone, CNa, sodium tetraborate, water for injection	Parasympathomimetic action, produces miosis and reduces intraocular pressure
Liquifilm Lágrimas® (Allergan/Ireland): lubricant: discard a month after opening bottle	14 mg/ml polyvinyl alcohol (DCI)	0.05 Benzalkonium chloride, dibasic sodium phosphate, CNa, monosodium phosphate, edetate disodium, hydrochloric acid, and sodium hydroxide (para pH), water for injection	Ocular lubricant
Vistafrin Liquifilm® (Allergan/Ireland): lubricant	1.2 mg/ml phenylephrine hydrochloride, with 14 mg/ml liquifilm (polyvinyl alcohol)	Benzalkonium chloride, acetate sodium, dibasic sodium phosphate, monosodium phosphate, antipirine, sodium tiosulfate, edetate disodium, hydrochloric acid, and sodium hydroxide, purified water	To relieve ocular congestion
Celluvisc® (Allergan/Ireland): lubricant	4 mg sodium carmelosa (DCI)	CNa, sodium lactate, CLK, calcium chloride, water for injection	Ocular lubricant

active ingredient by altering corneal penetration through changes in the degree of ionization; and, finally, to optimize product stability.

According to Carney and Hill,⁹ the physiological pH is 7.45, and the ocular range is between 6.6 and 7.80 pH units. For maximum comfort, an ophthalmic solution should have the same pH as the lacrimal fluid, or the pH of the solutions should lie within the ocular comfort range. Sev-

eral studies show that the pH of contact lens solutions is maintained within ocular comfort range; therefore, these solutions are well-tolerated.¹⁰⁻¹⁵

The most common active ingredients found in ophthalmic solutions are salts formed from weak bases, which are most stable at an acidic pH. Thus, the formulator is often faced with the need to choose a pH that does not compromise the stability of the product, but is still compatible with

Table 3. Mean, standard deviation (SD), range, and p values for the ophthalmic solutions evaluated

Ophthalmic solution	Mean	SD	Range		p value
Gentamicina®	6.61	0.02	6.58	6.62	<0.001
Oftalar®	7.64	0.03	7.58	7.69	0.055
Cusimolol®	6.92	0.02	6.88	6.96	<0.001
Elebloc®	6.69	0.02	6.64	6.73	<0.001
Oftalmotrim Dexta®	7.33	0.03	7.28	7.39	<0.001
Liquifilm®	7.24	0.04	7.17	7.29	0.718
Celluvisc®	7.20	0.05	7.11	7.28	0.370
Vistafrim®	6.89	0.02	6.86	6.91	0.002
Xalatan®	6.77	0.02	6.73	6.79	<0.001
Atropina®	5.18	0.03	5.13	5.24	0.168
Oftalmotrim®	5.79	0.04	5.73	5.85	0.011
Alomide®	5.09	0.11	5.00	5.44	0.045
Cortofal®	5.25	0.05	5.13	5.30	0.255
Poly-Pred®	6.44	0.03	6.38	6.50	<0.001
Ciclopléjico®	3.55	0.03	3.51	3.59	0.117
Anestésico®	4.70	0.11	4.53	4.84	0.904
Pilocarpina®	3.72	0.03	3.66	3.76	<0.001

the ocular surface. The solution to this dilemma is usually to maintain the product at an acid pH with a low-capacity buffer. Provided the drug itself has a weak buffering effect and the volume instilled is small, the tears should be able to adjust the pH rapidly to a value near 7.45, thereby minimizing any discomfort. However, occasionally the drug itself may exert a significant buffering effect and thus a different salt form may be necessary.¹⁶

The purpose of this article is to evaluate the pH value of 17 ophthalmic solutions frequently used in ophthalmic practice in Spain—some of these in worldwide distribution—and to investigate their variation over time. For this, measurements were taken over a test period of 30 days, which is the recommended period of use after the bottles have been opened. The pH values will determine the solutions that are most compatible with ocular physiology and are more stable during the time (30 days) of the study.

Materials and Methods

Seventeen ophthalmic drugs were selected for pH measurement and comparison in this study. Tables 1 and 2 show the solutions evaluated, their trade names, manufacturing laboratory, composition and action, observations, indication for use, and recommended time of use once the bottle is opened.

For statistical purposes, we used 15 bottles of each solution, chosen at random from different pro-

duction lots, in order to obtain a general mean pH value for that particular solution, not the pH of one specific lot.

Using a micropH 2002 Crison pH-meter,¹⁷ the pH values of the solutions were measured over a 30-day period after the bottles were opened, as this was the maximum length of use recommended by the manufacturer. The pH-meter, which uses an Ingold electrode sensor, measures electric potential differences with a high-entry impedance (10^{14} Ohms) and high resolution (0.1 mv), giving precise readings. The accuracy and repeatability of the pH-meter are ± 0.001 and ± 0.002 pH units, respectively.

Measurements were randomized. A 0.005-ml increment was taken from each bottle and was measured daily. The pH value was measured five times for each sample. The electrode sensor was rinsed with distilled water between measurements. The pH-meter was calibrated using two standard buffered solutions of 7.02 and 4.00 pH units before the first measurement, after 10 measurements, and after the final measurement.

All solutions were tested at room temperature, ranging from 19° to 21° C, and the humidity was maintained at 65% (by air conditioner) during the testing period. The Xalatan® and the Oftalmotrim Dexta® were kept in a refrigerator for 30 days; the rest of the solutions were kept at room temperature.

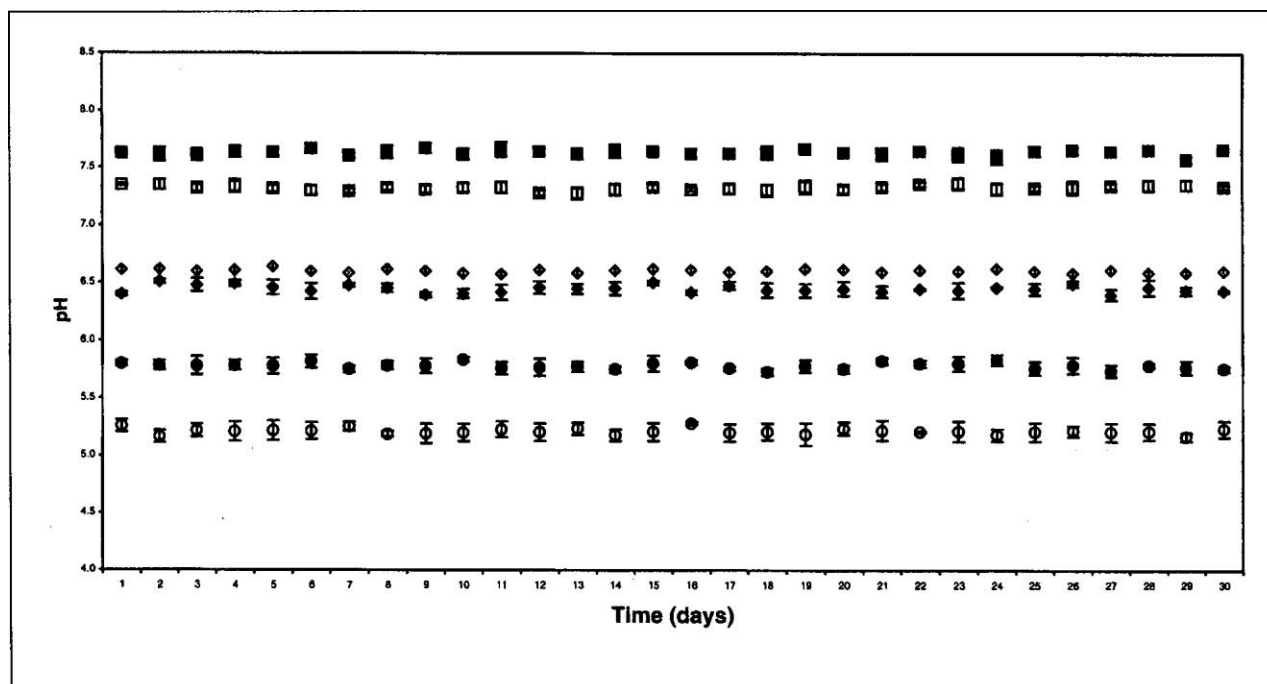


Figure 1 The mean pH values and standard deviations of ophthalmic solutions evaluated over the 30-day testing period. ◇ = Gentamicina®; ■ = Oftalar®; □ = Oftalmotrim Dexta®; ● = Oftalmotrim®; ○ = Cortoftal®; and ◆ = Poly-Pred®.

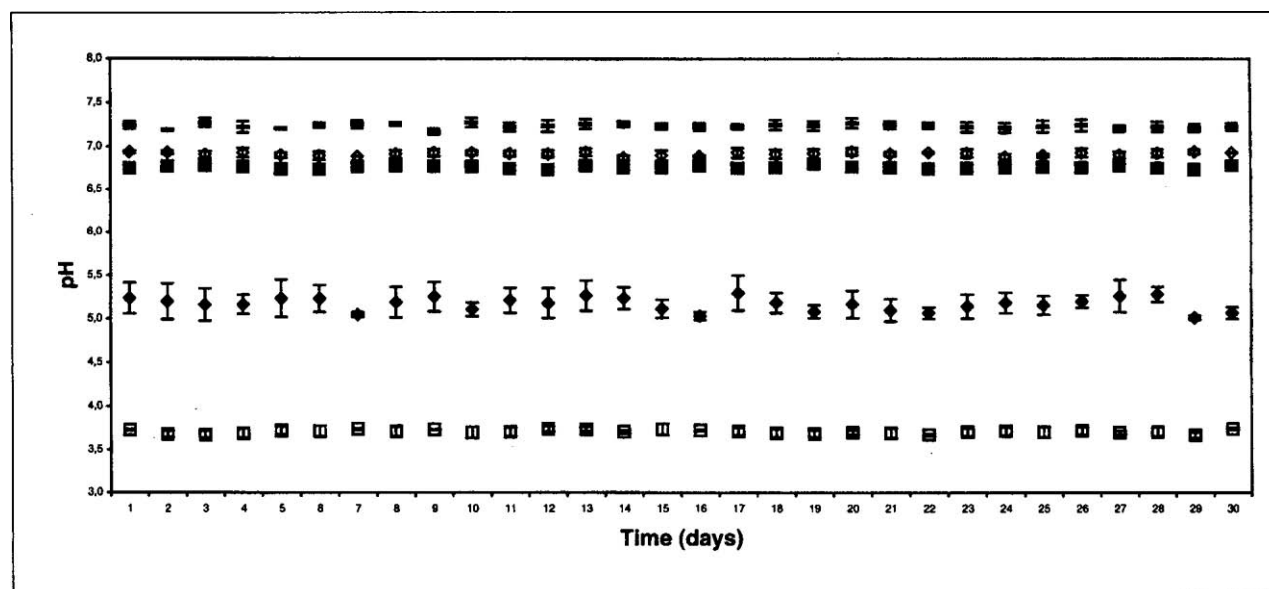


Figure 2 The mean pH values and standard deviations of ophthalmic solutions evaluated over the 30-day testing period. ◇ = Cusimolol®; — = Liquifilm®; ■ = Xalatan®; ● = Alomide®; and □ = Pilocarpina®.

Results

Figures 1, 2, and 3 show the pH values obtained over 30 days for all the solutions. The pH of each solution changed over time. However, using the one-way analysis of variance (ANOVA) test¹⁸ with the criterion of $p > 0.01$, we did not find statistically significant differences in pH over time for 10 of the 17 solutions analyzed: Cortoftal®, Ofta-

lar®, Oftalmotrim®, Alomide®, Colircusi Ciclopéjico®, Colircusi Atropina®, Colircusi Anestésico® (4:1), Liquifilm Lagrimas®, Vistafrin Liquifilm®, and Celluvisc®.

The rest of the solutions—seven of the 17 solutions studied—presented statistically significant variations on isolated days, as follows:

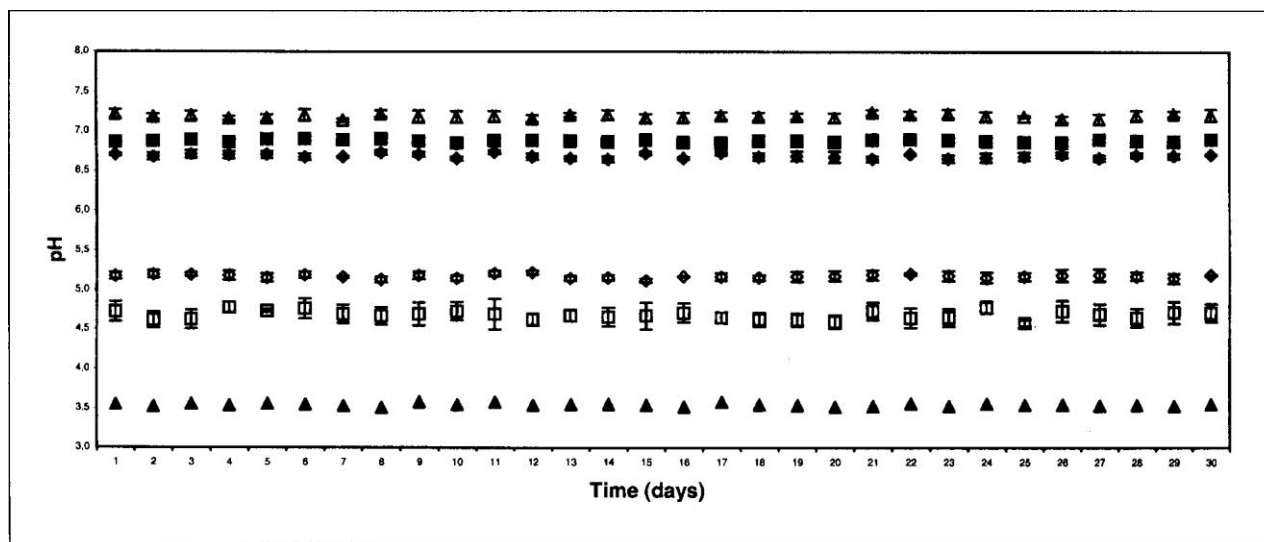


Figure 3 The mean pH values and standard deviations of ophthalmic solutions evaluated over the 30-day testing period. ♦ = Elebloc®; ■ = Vistafrin®; △ = Celluvisc®; ◇ = Atropina®; ▲ = Ciclopléjico®; and □ = Anestésico®.

Colircusi Gentamicina® (4:1) presented a significant variation on Day 22 in relation to Day 7;

Elebloc® 2 presented a variation on Day 16 in relation to Day 2, Day 22, and Day 30;

Oftalmotrim Dexta® presented variation on Day 7 in relation to Day 2 and Day 22;

Colircusi Pilocarpina® 2 presented significant variation on Day 22 in relation to all other Days;

Poly-Pred® presented variation on Day 7 in relation to Day 2, on Day 16 in relation to Day 7, on Day 22 in relation to Day 2, and on Day 30 in relation to Day 7; and

Xalatan® presented variation on Day 7 in relation to Day 2, on Day 16 in relation to Day 2, on Day 22 in relation to Day 7 and Day 16, and on Day 30 in relation to Day 2 and Day 16.

It should be noted that Cusimolol® (4:1) presented a significant variation from Day 22 after the opening of the bottle to the thirtieth day.

The mean average standard deviations (SDs) and range of the pH values of the ophthalmic solutions measured are shown in Table 3. All the solutions had mean pH values that ranged from 7.69 and 3.51 pH units. The pH values for nine solutions lie well within the ocular comfort range:¹³ Colircusi Gentamicina® (4:1), Oftalar®, Cusimolol®, Elebloc®, Oftalmotrim Dexta®, Liquifilm®, Celluvisc®, Vistafrin Liquifilm®, and Xalatan®. The remaining eight solutions—Colircusi Atropina® (4:1), Oftalmotrim®, Alomide®, Cortof-

tal®, Poly-Pred®, Colircusi Ciclopléjico®, Colircusi Anestésico® (4:1), and Colircusi Pilocarpina® 2—presented pH values below the minimum value of the ocular comfort range. The standard deviation values over time ranged from 0.02 to 0.11, depending on the solution tested.

Discussion

Figures 1, 2, and 3 indicate that the pH values of all the solutions evaluated fluctuated over time. These low variations in pH over time are secondary to the action of the buffer agent, which functions to maintain the pH. The differences obtained may be due to the different buffer agents used in the specific solutions.

The buffer agents present in the studies of ophthalmic solutions are phosphate, citrate, citrate-phosphate, bicarbonate, acetate, and borate.^{19,20} The buffering agents found in the ophthalmic solutions studied without statistically significant pH variations over time are phosphate, borate, and citrate. The most-used buffer agent is phosphate. The buffer agents present in the solutions with statistically significant pH variations are phosphate, acetate, citrate, and borate. We do not find a relation between pH variation and buffer agents. These solutions contained isotonic agents and preservatives that also react with air, modifying the solution pH value.

The solutions that do not present statistically significant pH variations over time are Cortoftal®,

Oftalar®, Oftalmotrim®, Alomide®, Colircusi Ciclopéjico®, Colircusi Atropina® (4:1), Colircusi Anestésico® (4:1), Liquifilm Lagrimas®, Vistafrin Liquifilm®, and Celluvisc®.

The solutions that presented isolated variations and maintained the original pH value on most of the 30 Days studied are: Colircusi Pilocarpina® 2%, Elebloc® 2, Colircusi Gentamicina® (4:1), Oftalmotrim Dexa®, Poly-Pred®, and Xalatan®. The isolated variations could be due to insufficient buffer agent, but the cause of the isolated pH variations is not clear.

We need to draw attention to Cusimolol® (4:1), since it presented statistically significant pH variations from Day 22 through Day 30. In this case the pH change could be due to insufficient buffer. The mean pH values from Day 22 to Day 30 ranged from 6.931 to 8.930 pH units. These variations are indeed minimal. Therefore, a clinical study of Cusimolol® (4:1) to verify that these pH variations do not affect the therapeutic action of the ophthalmic solution should be performed.

In spite of the variations, the pH values of all the evaluated solutions are at a tolerable level for the ocular surface.

In this study, we obtained a group of nine solutions—Elebloc®, Cusimolol® (4:1), Colircusi Gentamicina® (4:1), Oftalmotrim Dexa®, Liquifilm®, Vistafrin®, Celluvisc®, Xalatan®, and Oftalar®—that present a pH value within the ocular comfort range and do not affect ocular physiology. Within this group of solutions, the artificial tear solutions may be highlighted: Liquifilm® and Celluvisc® and the vasoconstrictor-ocular decongestant, Vistafrin Liquifilm®. The pH value of these solutions must be close to the physiological pH for maximum ocular comfort,^{21,22} since these solutions are prescribed to return the tears to a normal pH.

The other eight solutions—Oftalmotrim®, Colircusi Atropina® (4:1), Colircusi Ciclopéjico®, Colircusi Anestésico® (4:1), Colircusi Pilocarpina® 2, Alomide®, Cortoftal®, and Poly-Pred®—have a slightly acid pH. The difference between the lacrimal pH and ophthalmic solution pH will initially produce discomfort and lacrimation.

Consequently, in these cases, an initial decrease of ocular comfort is necessary to increase

absorption and improve the therapeutic effect of the ophthalmic solution; in the case of frequent use of the solution, we must take into account the question of whether the benefit is greater than the discomfort produced. It is the task of the dispensing doctor to decide whether extended use is appropriate.

Conclusions

The solutions with a more-stable pH during the test period were Cortoftal®, Oftalar®, Oftalmotrim®, Alomide®, Colircusi Ciclopéjico®, Colircusi Atropina® (4:1), Colircusi Anestésico® (4:1), Liquifilm Lagrimas®, Vistafrin Liquifilm®, and Celluvisc®, and the solutions with a pH closer to physiologic pH were Elebloc®, Cusimolol® (4:1), Colircusi Gentamicina® (4:1), Oftalmotrim Dexa®, Liquifilm®, Vistafrin®, Celluvisc®, Xalatan®, and Oftalar®.

In conclusion, in this study we evaluated the pH of 17 ophthalmic solutions and their evolution over a period of 30 days, obtaining a fluctuation in pH, which for most of the solutions is not statistically significant.

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References

1. Ahmed I, Gokhale RD, Shah MV, et al. Physiochemical determinants of drug diffusion across the conjunctiva, sclera, and cornea. *J Pharm Sci* 1987;76:583-6.
2. Ahmed I and Patton TF. Importance of the noncorneal absorption route in topical ophthalmic drug delivery. *Invest Ophthalmol Vis Sci* 1985;26:584-7.
3. Ashton P, Podder SK, Lee VH. Formulation influence on conjunctival penetration of four beta blocker in the pigmented rabbit: a comparison with corneal penetration. *Pharm Res* 1991;8(9):1166-74.
4. Berg MJ, Lantz RK, Schoenwald RD, et al. Optimization of pharmacokinetic monitoring: I. Linear pharmacokinetics. *Ther Drug Monit* 1983;5(4):379-87.
5. Huang HS, Schoenwald RD, Lach JL. Corneal penetration behavior of beta-blocking agents. II. Assessment of barrier contributions. *J Pharm* 1983;72:1272-9.
6. Burstein NL and Anderson JA. Corneal penetration and ocular bioavailability of drugs. *J Ocul Pharmacol* 1985; 1(3):309-26.

7. Shih RL and Lee VH. Rate limiting barrier to the penetration of ocular hypotensive beta blockers across the corneal epithelium in the pigmented rabbit. *J Ocul Pharmacol* 1990;6(4):329-36.
8. Ramer RM and Gasset AR. Ocular penetration of pilocarpina: the effect of pH on the ocular penetration of pilocarpina. *Ann Ophthalmol* 1975;7(2):293-6.
9. Carney LG and Hill RM. Human tear pH: diurnal variations. *Arch Ophthalmol* 1976;94:821-4.
10. Demas GN. pH consistency and stability of contact lens solutions. *J AM OPTOM ASSOC* 1989;60:732-4.
11. Harris MG, Higa CK, Lacey LL, et al. The pH of aerosol saline solution. *Optom Vis Sci* 1990;67:84-8.
12. Harris MG, Hernandez GN, Nuno DM. The pH of hydrogen peroxide disinfection systems over time. *J AM OPTOM ASSOC* 1990;61:171-4.
13. López-Alemany A, Montés-Micó R, Andrió A. Comparative study of pH for different saline and multipurpose contact lens solutions. *Contact Lens & Anterior Eye* 1997;20:91-5.
14. Montés-Micó R and López-Alemany A. Change in pH of two-step hydrogen peroxide disinfection systems available on the Spanish market. *ICLC* 1998;25:7-10.
15. Montés-Micó R and López-Alemany A. Comparative study of the pH over time of use of contact lens saline solutions. *ICLC* 1998;25:11-5.
16. Suhonen P, Jarvinen T, Koivisto S, et al. Different effects of pH on the permeation of pilocarpine and pilocarpine prodrugs across the isolated rabbit cornea. *Eur J Pharm Sci* 1998;6:169-76.
17. *MicroPH 2002 Crison pH-meter instrument manual*. Polígono Industrial 6: Madrid, Spain, 1987.
18. Hand DJ and Taylor CC. *Multivariate analysis of variance and repeated measures*. London: Chapman & Hall, 1993.
19. Winkler BS and Trese MT. The pH of antibiotic vitreous infusion combinations: a potential cause of retinal toxicity. *Ophthalmic Surg* 1992;23:622-4.
20. Malhotra M and Majumdar DK. In vitro transcorneal permeation of Ketorolac tromethamine from buffered and unbuffered aqueous ocular drops. *Indian J Exp Biol* 1997;35:941-7.
21. López-Alemany A, Montés-Micó R, García-Valdecabres M. Do artificial tears have an adequate pH? *Contactologia* 1999;21:51-5.
22. López-Alemany A, Montés-Micó R, García-Valdecabres M. Ocular physiology and artificial tears. *J AM OPTOM ASSOC* 1999;70:455-60.

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