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Equilibrium study of copper absorption to different types of soft contact lens

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Abstract To measure binding affinity of copper, one of the heavy metals in particulate matter (PM) was applied to soft contact lenses made of two different materials because contact lenses are readily exposed to PM. Copper binding to ionized silicon hydrogel lens yielded an equilibrium association constant $K_{a,eq}$ value of 14.03 μM without color change of lens, compared to that of 19.16 μM for copper binding to de-ionized hydrogel lenses with color change of lens. The results indicated that the color change of lens is not consistent with the concentration of cooper deposition on lens, and copper bound relatively stronger in ionized silicon hydrogel lens than in de-ionized hydrogel lens. Therefore, the continuous exposure of contact lenses to high PM levels might lead to heavy metal deposition on the lens, which would be detrimental to ocular health.

Keywords Binding affinity · Copper · Equilibrium association constant · Hydrogel lens · Particulate matter

Introduction

Particular matter (PM), known as particle pollution, is a complex mixture of extremely small particles including acids, organic chemicals, metals and dust, and liquid droplets [1]. PM levels have increased over the past decades in Asia [2, 3]. Exposure to PM affects both the lungs and heart, resulting in asthma, irritation of the airways, irregular heartbeat, heart attacks, and cancers [4, 5]. PM is also associated with ocular toxicity [6, 7]. Exposure to PM causes ocular irritation, discomfort and unstable vision in severe cases [8, 9].

Copper is of increasing interest as an environmental pollutant because it is one of the heavy metals [10] and is a transition metal component thought to be particularly harmful as it has the potential to produce reactive oxygen species causing disease over time [11]. Even though contact lenses are commonly used to correct vision, little is known about the direct influence of copper or metals in PM on contact lenses. The most of metal absorption studies have been worked in the field of material sciences and environmental engineering. They focused on investigating metal uptake ability of absorbent materials including hydrogel lens material [12–14]. So, there is no indication of exact metal binding affinity on lens. Also, the biological relevance studies for contact lenses have been mainly subjected to not a metal deposition but protein and lipids absorption [15, 16].

In this study, the absorption of copper to both ionized and non-ionized hydrogel lenses was directly examined using UV–Vis spectrophotometer. We firstly reported a simple method of measuring the binding of copper to lenses and then characterized the binding affinity of copper on lenses.

Materials and methods

Contact lens

Daily disposable contact lenses, Biotrue ONEDAY (Bausch + Lomb) and 30-day contact lenses, PureVision2 (Bausch + Lomb) were used. The most important parameters of the lenses are summarized in Table 1.

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Table 1 Properties of contact lenses

Proprietary name	Biotrue ONEDAY	PureVision2
Materials	NesofilconA	BalafilconA
Water contents (%)	78	36
FDA group	II	V-Cm
Dk	42	112
Diameter	14.2 mm	14.0 mm
Base curve	8.6 mm	8.6 mm

Copper absorption

Contact lenses were soaked three times in ultra-trace elemental analysis-grade water (Fisher Scientific) for 10 min each to remove residual lens solution. Then, contact lenses were incubated with different concentrations of copper (II) sulfate (Sigma-Aldrich) solution; 5 ml of 10, 25, 50, 100, 150 and 200 µM on 6-well cell-culture plate. The plate containing lens and copper solution was gently shaken on agitator. Then, the color changes of contact lenses were observed, and absorbance of copper solution was monitored.

Equilibrium analysis of copper binding to lenses

Aqueous copper solutions exhibit maximum absorbance at 200 nm [17]. Absorption spectra of copper solution were monitored at 200 nm using a Sinco spectrophotometer. The absorption spectra of copper solution were measured before and after soaking the contact lenses when the system had reached equilibrium. Equilibrium binding of copper was checked by recording absorbance of copper solution having lenses at 200 nm every 3 min for initial 30 min and then every 10 min for last 30 min. It was believed that the copper had reached to equilibrium because the absorbance was constant after 3 min till 1 h. The magnitude of copper binding on lenses was calculated based on the spectral changes at 200 nm; copper solution without lenses minus copper solution with lenses. The experimental procedure was the same for all measurement points (10, 25, 50, 100, 150 and 200 µM). These data were analyzed using Eq. 1 [18] in which Y is the bound copper concentration on lenses corresponding to the absorbance change of copper solution at 200 nm, $Y_{\max}$ is the maximum copper-binding concentration, and $K_{a,eq}$ is the apparent K_a value obtained from the equilibrium measurements. Equation 1 is a modified Michaelis–Menten or Langmuir equation to explain generic adsorption of bimolecular species into surfaces

$$Y = Y_{\max}[Cu^{2+}]/\left(K_{a,eq} + [Cu^{2+}]\right). \quad (1)$$

Results and discussion

Changes in contact lens color

Biotrue ONEDAY lenses changed color after copper absorption from aqueous copper solution (Fig. 1A). The lenses turned blue after exposure to 10 and 25 µM copper solution and greener at higher concentrations. At 200 µM, the Biotrue ONEDAY lenses turned completely green. Interestingly, PureVision2 lenses did not change color upon incubation in the copper solutions. The incubation time was extended to exclude any effect of absorption time. After 1 h of incubation, the color of lenses was unchanged irrespective of the copper concentration (Fig. 1B).

Original FDA group II hydrogel contact lenses are composed of 2-hydroxy-ethyl methacrylate (polyHEMA) crosslinked with ethylene glycol dimethacrylate. They are copolymerized with *N*-vinylpyrrolidone to improve their water content [19] by forming hydrogen bonds with two molecules of water. The surface of group II hydrogel contact lenses is de-ionized to reduce the negative charge preventing to bind positively charged proteins, but it might not completely de-ionized. It was indicated that the uptake of cation drug was directly bound to the anionic ligands in the de-ionized polyHEMA gel [20]. As the same reason, treatment of Biotrue ONEDAY lenses with copper solution results in Cu^{2+} ion binding to the partially negatively charged surface due to the hydroxyl group of HEMA, which leads to a color change. The greater the quantity of Cu^{2+} ion bound to the lens, the darker is the color of the lens.

Purevison2 belongs to FDA group V-Cm. Its monomer includes tris (trimethylsiloxy) silylpropyl vinyl carbamate (TPVC) [21]. The TPVC molecule contains a hydrophobic silicone linked to a hydrophilic vinyl carbamate group, resulting in marked polarity. The surface of FDA group V-Cm lenses is non-ionic, but the vinyl carbamate group of TPVC is in its ionized form at pH 6–8. Copper sulfate is normally ionized in water to form the Cu^{2+} ion resulting in over pH 6 solution (data not shown). FDA group V-Cm lenses have an ionic surface at pH 6, and the vinyl carbamate group of TPVC in silicone hydrogel lenses provides a greater negative charge than the hydroxyl group of HEMA in FDA group II lenses. Therefore, the PureVision2 lens theoretically might take up a greater quantity of Cu^{2+} ion leading to a darker color than Biotrue ONEDAY lenses. However, the color of PureVision2 lenses was not changed. It suggests that the bound copper may be status of Cu^{1+} rather than Cu^{2+}. Binding Cu^{2+} ions on lenses should be reduced by the vinyl carbamate group of TPVC material because the vinyl carbamate group functions as an electron donator [22] causing a loss of Cu^{2+} color.

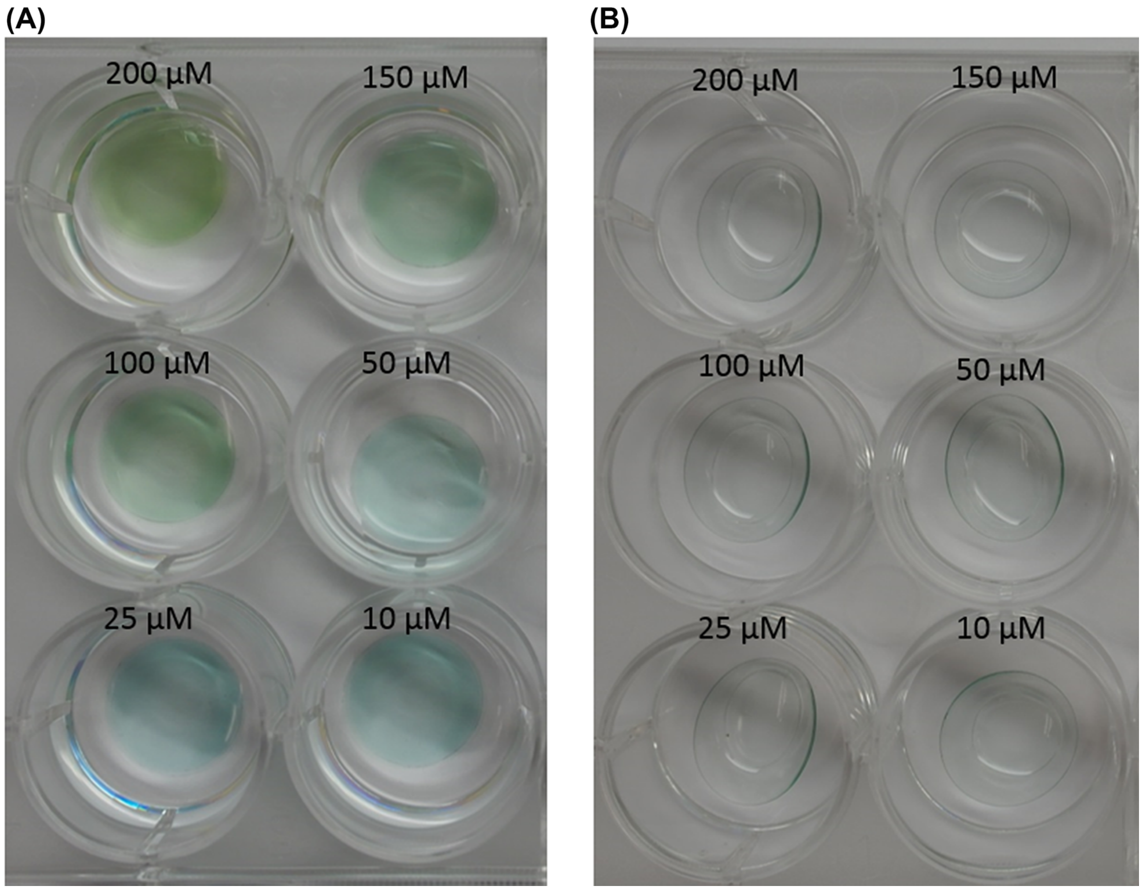

Fig. 1 Color of Biotrue ONEDAY lenses (**A**) and PureVision2 lenses (**B**) after soaking in various concentrations of copper. Each concentration of copper solution was indicated on wells

Equilibrium analysis of copper binding

The stoichiometric ratio between copper and absorbance is evaluated in Fig. 2. The plot of absorbance versus mole fraction of copper showed a linear regression ($R^2 = 0.99$).

Comparison of the absorption spectra of copper before and after soaking of Biotrue ONEDAY lenses in copper solution revealed that the absorbance was significantly reduced. The difference in the absorption spectra corresponded to the copper concentration deposited on lenses. The same pattern was observed for PureVision2 lenses with more marked changes resulting in more copper bound to the PureVision2 lenses. It indicates that color change of copper deposition on lenses is not a critical factor to judge copper binding on lens.

The equilibrium binding of copper to lenses was determined by the fit of bound copper concentration on lenses to Eq. 1. A bound copper amount was calculated by linear regression fit in Fig. 2. It yielded an equilibrium association constant ($K_{a,eq}$) of 19.16 ± 3.42 µM and maximum magnitude of copper binding (Y_{max}) of 20.94 ± 0.89 µM for Biotrue ONEDAY lenses (Fig. 3A), and $K_{a,eq}$ of 14.03 ± 1.63 µM and Y_{max} of 31.43 ± 0.77 µM for PureVision2 lenses (Fig. 3B). $K_{a,eq}$ value of PureVision2 is significantly smaller than that of Biotrue ONEDAY. These results reveal that the copper-binding affinity of PureVision2 lenses is greater than that of Biotrue ONEDAY lenses.

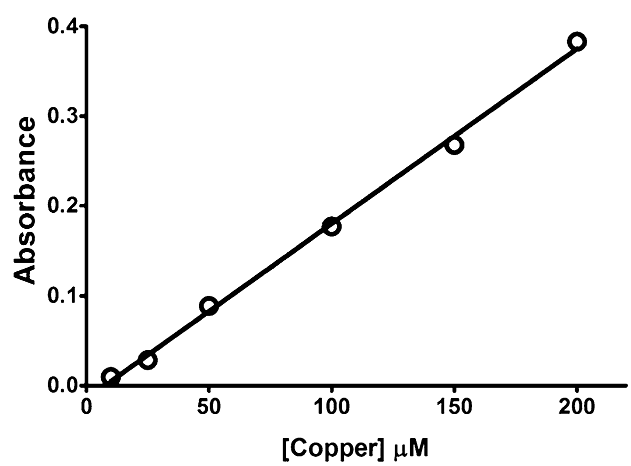

Fig. 2 The stoichiometric ratio between mole fraction of copper and absorbance at 200 nm

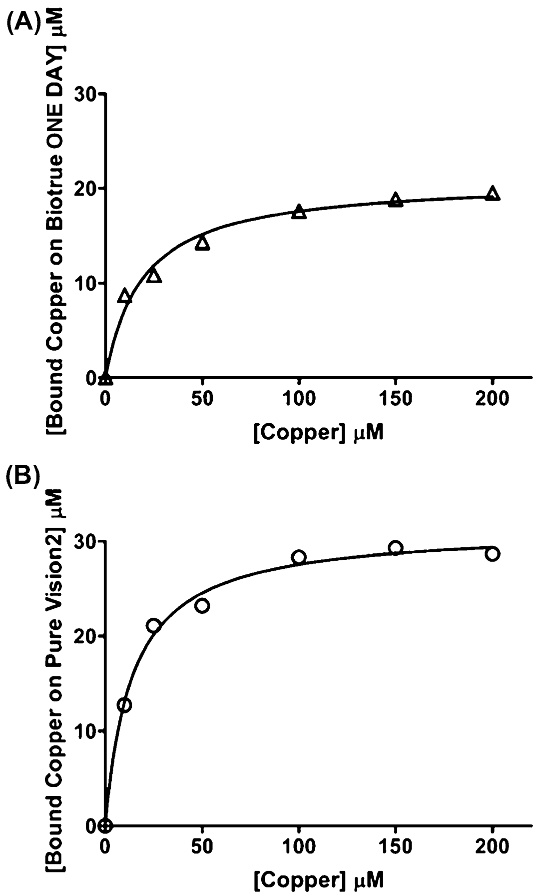

Fig. 3 Equilibrium binding of copper to Biotrue ONEDAY (**A**) and PureVision2 (**B**). Bound copper concentration was calculated after the system had reached equilibrium. The experiment was performed three times, and the average values were applied. The *line* is a fit of the data to Eq. 1

Normal concentration of copper in atmospheric PM, <1 μM, was not able to be tested due to copper detection limit by UV–Vis spectrophotometer. However, it should be considered that lenses are usually worn more than 1 day. If lenses are exposed to PM over 1 day, copper deposition should be accumulated day by day. In Fig. 3, it exhibits copper absorption on lens even at 10 μM of copper solution within 3 min and saturation behavior over 100 μM of copper, suggesting that copper might irreversibly bind on lenses very fast and continuously bind up to 100 μM of copper environment. Therefore, long-term exposure of contact lenses to high levels in PM might lead to accumulation of heavy metal on lenses, which would be detrimental to ocular health. Thus, the health implications of PM with respect to binding to the lens surface and toxicity to the eye warrant further investigation.

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References

1. Kim KH, Kabir E, Kabir S (2015) A review on the human health impact of airborne particulate matter. Environ Int 74:136–143
2. Fang GC, Huang YL, Huang JH (2010) Study of atmospheric metallic elements pollution in Asia during 2000–2007. J Hazard Mater 180:115–121
3. Wu YS, Fang GC, Lee WJ, Lee JF, Chang CC, Lee CZ (2007) A review of atmospheric fine particulate matter and its associated trace metal pollutants in Asian countries during the period 1995–2005. J Hazard Mater 143:511–515
4. Anderson JO, Thundiyil JG, Stolbach A (2012) Clearing the air: a review of the effects of particulate matter air pollution on human health. J Med Toxicol 8:166–175
5. Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287:1132–1141
6. Pinazo MD, Gallego R, Garcia JJ, Zanon I, Nucci C, Dolz-Marco R, Martinez S, Galbis-Estrada C, Marco C, Lopez MI, Galarreta DJ, Diaz M (2014) Oxidative stress and its downstream signaling in aging eyes. Clin Interv Aging 9:637–652
7. Torricelli AM, Novaes P, Matsuda M, Alves MR, Monteiro MLR (2011) Ocular surface adverse effects of ambient levels of air pollution. Arq Bras Oftalmol 74:U366–U377
8. Chang CJ, Yang HH, Chang CA, Tsai HY (2012) Relationship between air pollution and outpatient visits for nonspecific conjunctivitis. Invest Ophth Vis Sci 53:429–433
9. Fujishima H, Satake Y, Okada N, Kawashima S, Matsumoto K, Saito H (2013) Effects of diesel exhaust particles on primary cultured healthy human conjunctival epithelium. Ann Allergy Asthma Immunol 110:39–43
10. Silva LO, Leao DJ, dos Santos DC, Matos GD, de Andrade JB, Ferreira SL (2014) Determination of copper in airborne particulate matter using slurry sampling and chemical vapor generation atomic absorption spectrometry. Talanta 127:140–145
11. Uriu-Adams JY, Keen CL (2005) Copper, oxidative stress and human health. Mol Asp Med. 26:268–298
12. Krysztofiak K, Szyczewski A, Kruczynski Z (2014) Investigation of copper and manganese ion diffusion through hydrogel contact lens materials using ESR technique. Pol J Environ Stud. 23:363–371
13. Lebrun L, Vallee F, Alexandre B, Nguyen QT (2007) Preparation of chelating membranes to remove metal cations from aqueous solutions. Desalination 207:9–23
14. Sharaf M, Arida A, Sayedd SA, Younis A, Faraq A (2009) Separation and preconcentration of some heavy-metal ions using new chelating polymeric hydrogels. J Appl Pol Sci. 113:1335–1344
15. Luensmann D, Jones L (2012) Protein deposition on contact lenses: the past, the present and the future. Con Lens Ant Eye 35:53–64
16. Panaser A, Tighe JB (2012) Function of lipids—their fate in contact lens wear: an interpretive review. Con Lens Ant Eye 35:100–111
17. Lutfullah Sharma S, Rahman N, Azmi SNH, Iqbal B, Amburk MIBB, Al Barwani ZMH (2010) UV spectrophotometric determination of Cu(II) in synthetic mixture and water samples. J Chin Chem Soc Taip 57:622–631
18. Shin S, Feng ML, Chen Y, Jensen LMR, Tachikawa H, Wilmot CM, Liu AM, Davidson VL (2011) The tightly bound calcium of MauG is required for tryptophan tryptophylquinone cofactor biosynthesis. Biochemistry-Us 50:144–150
19. Ramamoorthy P, Sinnott LT, Nichols J (2010) Contact lens material characteristics associated with hydrogel lens dehydration. Ophthal Physl Opt 30:160–166

20. Sato T, Uchida R, Tanigawa H, Uno K, Murakami A (2005) Application of polymer gels containing side-chain phosphate groups to drug-delivery contact lenses. J Appl Polym Sci 98:731–735
21. Zhao ZJ, Camt NA, Aliwarga YL, Wei XJ, Naduvilath T, Garrett Q, Korth J, Willcox MDP (2009) Care regimen and lens material influence on silicone hydrogel contact lens deposition. Optom Vis Sci 86:251–259
22. Kumar K, Castano E, Weidner A, Yildirim A, Goodwin A (2016) Depolymerizable poly(*O*-vinyl carbamate-*alt*-sulfones) as customizable macromolecular scaffolds for mucosal drug delivery. ACS Macro Lett 5:363–640