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# Drying methods for XPS analysis of PureVision™, Focus® Night&Day™ and conventional hydrogel contact lenses

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## Abstract

The surface composition of hydrogel contact lenses that contain silicon-based monomers, PureVision™ (balafilcon A) and Focus® Night&Day™ (lotrafilcon A), were investigated by X-ray photoelectron spectroscopy (XPS). Conventional and daily disposable hydrogel lenses based on hydroxyethyl methacrylate (HEMA) were also studied, with the commonly prescribed 1-day Acuvue® lens (etafilcon A) used as a control. All the lenses were pre-washed and dehydrated by three different methods, including drying in air, drying in nitrogen or freezing with subsequent freeze-drying, before the XPS analysis. The lenses dried in air had more impurities on the surface, and the lenses that were freeze-dried lost transparency, suggesting that drying lenses in nitrogen is the preferred preparation method for XPS analysis. Surface compositions for all lens materials were obtained and this data can be used as a control/base-value for future analysis of the interactions of soft contact lens materials with chemicals such as drugs or tear components.

*Keywords:* Hydrogel contact lenses; Silicone hydrogels; Siloxane hydrogels; Silicon-based hydrogels; X-ray photoelectron spectroscopy

## 1. Introduction

With over 70 million users world-wide, contact lenses belong to one of the most abundant categories of biomedical devices in clinical use. Currently, daily disposable (DD) soft contact lenses based on hydroxyethyl methacrylate (HEMA) and continuous wear (CW) soft contact lenses based on a silicon-containing material are rapidly gaining market share over the conventional daily wear (DW) soft contact lenses that are worn on a daily basis and cleaned prior to re-insertion. The monomer compositions of some of the more common HEMA-based soft contact lenses examined in the present study are presented in Table 1.

As described by Lopez-Alemany et al., HEMA-based hydrogel lenses are the second of five generations of contact lenses [1]. Although they were envisioned as early as 1960s [2], HEMA-based hydrogel lenses are still the most popular type of contact lens. These lens materials are copolymers of HEMA and

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Table 1
Monomer compositions of the lens materials[a]

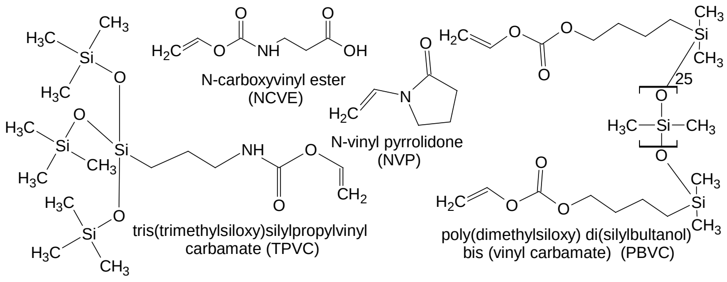
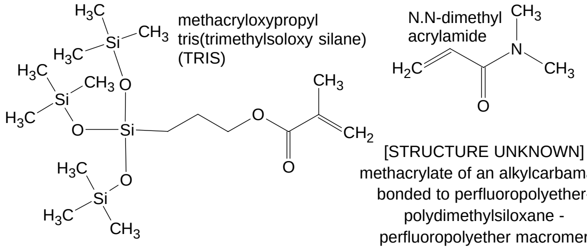
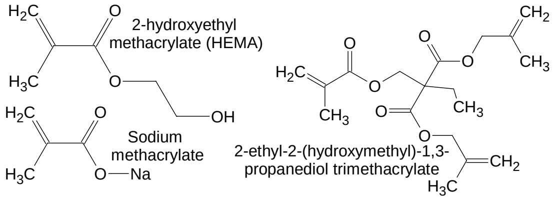
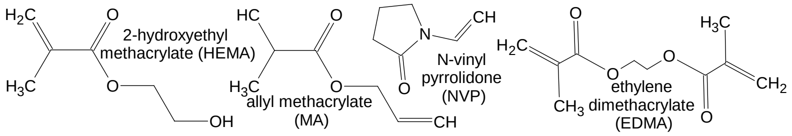
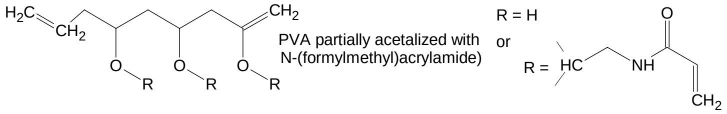
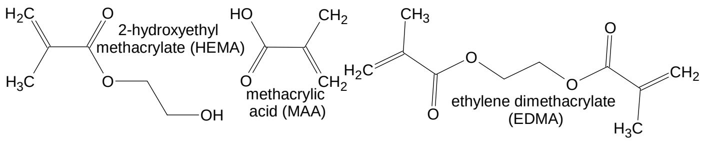
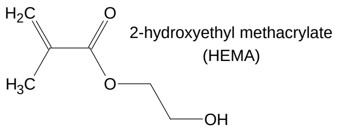
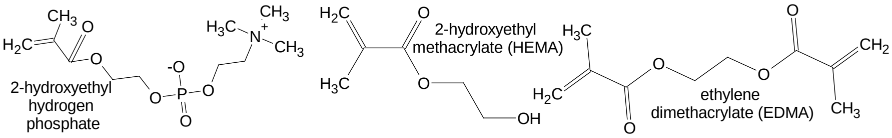
| | |
|---|---|
| Balafilcon A (CW) | <br>N-carboxyvinyl ester (NCVE)<br>N-vinyl pyrrolidone (NVP)<br>tris(trimethylsiloxy)silylpropylvinyl carbamate (TPVC)<br>poly(dimethylsiloxy) di(silylbultanol) bis (vinyl carbamate) (PBVC) |
| Lotrafilcon A (CW) | <br>methacryloxypropyl tris(trimethylsoloxy silane) (TRIS)<br>N.N-dimethyl acrylamide<br>[STRUCTURE UNKNOWN] methacrylate of an alkylcarbamate bonded to perfluoropolyether-polydimethylsiloxane - perfluoropolyether macromer |
| Etafilcon A (DD) | <br>2-hydroxyethyl methacrylate (HEMA)<br>Sodium methacrylate<br>2-ethyl-2-(hydroxymethyl)-1,3-propanediol trimethacrylate |
| Hilafilcon A (DD) | <br>2-hydroxyethyl methacrylate (HEMA)<br>allyl methacrylate (MA)<br>N-vinyl pyrrolidone (NVP)<br>ethylene dimethacrylate (EDMA) |
| Nelfilcon A (DD) | <br>PVA partially acetalized with N-(formylmethyl)acrylamide)<br>R = H or R = |
| Ocufilcon A (DD) | <br>2-hydroxyethyl methacrylate (HEMA)<br>methacrylic acid (MAA)<br>ethylene dimethacrylate (EDMA) |
| Polymacon (DW) | <br>2-hydroxyethyl methacrylate (HEMA) |

Table 1 (*Continued*)

| | |
|---|---|
| Omafilcon A (DW) |  |

[a] CW: continuous wear silicon-based hydrogel lens; DD: daily disposable HEMA-based hydrogel lens; DW: conventional daily wear HEMA-based hydrogel contact lens.

other hydrophilic or lipophilic monomers such as *N*-vinyl pyrrolidone (NVP) and methacrylates that contribute to the wide range of water contents of both ionic and non-ionic materials (Table 1). The water content is usually above 40 wt.%, which contributes to the softness and comfort of these lenses. However, the gas permeability of the lenses is limited by the permeability through the water phase of the lens, making the overnight removal of the DW lenses necessary. Subsequent lens re-insertion requires meticulous lens cleaning, and it is somewhat inconvenient. These lenses could typically be reused for periods up to 1 month before being replaced. Recently, with improved manufacturing techniques it has become economical to produce HEMA-based lenses for single use. These DD lenses are worn for a period of no more than 1 day and are never re-inserted after removal.

Silicon-based hydrogel lens materials are the fifth and the most recent generation of contact lens materials, which have also been called ‘‘silicone hydrogels’’, ‘‘siloxane hydrogels’’ and ‘‘high Dk soft lenses’’. Introduced in 1999, these lenses have the comfort of soft contact lenses, with significantly higher gas permeability due to a siloxane component. Their improved oxygen permeability has made it possible to wear these lenses on a continuous basis for up to 30 days and 30 nights without removal, hence the term ‘‘continuous wear lenses’’. Since their introduction these CW lenses already have more than 350,000 users. The two commercially available CW lenses are PureVision™ made of the material balafilcon A and Focus® Night&Day™ made of lotrafilcon A. The chemical compositions of these materials are proprietary, but the USAN registered components of balafilcon A (Table 1) are tris(trimethylsiloxy)silyl propyl vinyl carbamate (TPVC), NVP, *N*-carboxyvinyl ester (NCVE) and poly(dimethylsiloxy)di(silyl bultanol)-bis(vinyl carbamate) (PBVC). Due to its hydrophobic nature, TPVC in its basic form is not comfortable on the eye. Plasma oxidation is therefore used to increase the wettability of the surface. The known components of lotrafilcon A (Table 1) are a macromer of α,ω-terminated methacrylate of an alkylcarbamate covalently bonded to a triblock copolymer of perfluoroether–polydimethylsiloxane–perfluoroether, copolymerised with methacryloxyl propyl(trimethyl siloxy silane) and hydrophilic monomers such as *N*,*N*-dimethylacrylamide [1,3,4]. For comfort purposes, this material is also surface modified by a plasma polymerised coating of trimethylsilane, oxygen and methane [1,4]. Substantial differences of the material surface morphology resulting from the plasma treatment methods have been recently observed by Lopez-Alemany et al. using scanning electron microscopy [1]. Further morphological differences such as a macroporous structure observed for balafilcon A but not for lotrafilcon A may also be explained by the differences between the two plasma treatment methods. The surface compositions of these treated lenses have not yet been reported.

All contact lens materials can interact with chemicals, including both natural chemicals such as the proteins and lipids in the tears, and synthetic chemicals such as drugs or chemicals in the air (e.g. volatile organics) [5]. In order to study the interaction of chemicals with soft contact lenses, knowledge of the surface characteristics of clean/unworn lenses must first be obtained through a baseline or reference set of control values. X-ray photoelectron spectroscopy (XPS) is a powerful technique for determining the surface characteristics of soft contact lenses [6–8] and their interactions with tear components [8–10] or other chemicals [11]. Given that its detection level is typically 0.2 at.% [12], XPS (also known as electron spectroscopy for chemical analysis or ESCA) provides quantitative elemental and chemical state information about a surface. The sampling depth for this technique is approximately 1–30 nm, which encompasses a surface region highly relevant for bio-interactions. The depth of analysis depends on the mean free path, the kinetic energy and the emission direction of the emitted photoelectron. Surfaces of non-conductive materials (including soft contact lenses) could become positively charged during the analysis due to the emission of photoelectrons. This positive charge reduces the kinetic energy with which the photoelectrons are emitted and must be compensated for in order to obtain an accurate binding energy value. A low-energy electron flood gun can be used to prevent insulating samples from becoming charged during analysis [12,13]. Because the XPS technique is performed under ultra-high vacuum (UHV) conditions, hydrated materials must either be dried prior to analysis, or frozen and maintained in cryogenic conditions during analysis. Given that the latter requires considerably more elaborate instrumentation and effort, drying the sample ex situ before the analysis would be the preparation method of choice. The application of XPS to biomaterials is well described by Ratner [14] and Andrade [12]. Despite the use of the XPS technique for studying contact lenses since the early 1990s [9,15], the surfaces of soft contact lenses, particularly silicon-based lenses, have yet to be fully characterised. In particular, little attention has been given to the effect of sample preparation for the XPS analysis of these hydrated materials.

The purpose of this study is to provide surface composition data of representative commercially available soft contact lenses to serve as a benchmark for future studies. In particular, the lenses investigated in the present work include the two novel CW silicon-based soft lenses, four DD and two DW soft contact lenses. The effect of different drying methods on the surface composition of the lens is examined by XPS.

## 2. Methodology

Only new, unworn lenses were used in the present study. Triplicates of each of the two CW silicon-based hydrogel lenses, four DD and two DW lenses (Table 2) were each dehydrated by one of three methods: drying in air, drying in nitrogen and freezing followed by freeze-drying. Lenses were washed in de-ionised water for at least 15 min prior to the dehydration procedure. Excess water was removed from the lenses by carefully touching the outermost edge of the lens to a filter paper. The lenses were put on clean Petri dishes and dried in still, pre-dried air or nitrogen at room temperature, or immediately frozen to −80 °C and subsequently freeze-dried under reduced pressure, depending on which of the aforementioned drying methods was used.

XPS analysis was performed by using a multi-technique ultra-high vacuum Imaging XPS Microprobe system (Thermo VG Scientific ESCALab 250) equipped with a hemispherical analyser (of 150 mm mean radius) and a monochromatic Al K$\alpha$ (1486.60 eV) X-ray source. The high sensitivity of this instrument obtained at a routine instrumental energy resolution of 0.5 eV FWHM at 20 eV pass energy allowed us to characterise spectral features in the core-shell regions and to resolve valence band structure. The spot size for the XPS analysis used for the present work was approxi-

Table 2
Contact lens materials

| Category | Name (material) [short form] | Manufacturer | Ionic/ non-ionic | FDA group | Water content (wt.%) |
|---|---|---|---|---|---|
| Silicon-based hydrogels (CW) | PureVision™ (balafilcon A) [Bal] | Bausch & Lomb | Ionic | Group III | 36 |
| | Focus® Night&Day (lotrafilon A) [Lot] | CIBA | Non-ionic | Group I | 24 |
| Daily disposables, pHEMA-based (DD) | 1-Day Acuvue® (etafilcon A) [Eta] | Vistakon | Ionic | Group IV | 58 |
| | Soflens 1-day (hilafilcon A) [Hila] | Bausch & Lomb | Non-ionic | Group II | 70 |
| | Focus® dailies (nelfilcon A) [Nel] | CIBA | Non-ionic | Group II | 69 |
| | Ocular Sciences 1-day (ocufilcon B) [Ocu] | Ocular Sciences | Ionic | Group IV | 52 |
| Conventional, pHEMA-based (DW) | Optima (polymacon) [Poly] | Bausch & Lomb | Non-ionic | Group I | 39 |
| | Proclear (omafilcon A) [Oma] | Biocompatibles | Non-ionic | Group II | 62 |

mately 0.5 mm × 1.0 mm. Photoelectrons (escaped from the top 1–3 nm of the surface) were detected in the normal emission direction with an effective acceptance angle of ca. ±25° from the surface normal. After the drying treatments, the lenses were cut into small (<5 mm) sections, which were mounted on a stainless steel sample holder with double-sided carbon tapes. The sample was stored in vacuum ($2 \times 10^{-8}$ mbar) in the load-lock chamber of the Imaging XPS Microprobe system overnight to remove any remaining moisture before introduction into the analysis chamber maintained at $2 \times 10^{-10}$ mbar. A combination of low energy electrons and ions was used for charge compensation on the non-conducting lens material during the analysis conducted at room temperature.

An average of five high resolution XPS scans were performed for each element on a lens. Curve fitting was performed using CasaXPS VAMAS Processing Software and the binding energies of individual elements were identified with reference to the NIST X-ray Photoelectron Spectroscopy Database (NIST Standard Reference Database 20, version 3.2, web version) [16] and other XPS data handbooks [12,17]. Statistical analysis of the data was performed using multivariate ANOVA and Scheffé's post-hoc comparison test with significance taken at $P < 0.05$ (95% confidence).

## 3. Results and discussion

The surface composition and the effect of drying for the two commercially available CW contact lens materials along with the four DD and two DW lenses were investigated by XPS. Fig. 1 shows typical XPS survey spectra for etafilcon A (DD), balafilcon A (CW) and lotrafilcon A (CW), all prepared by drying in nitrogen, depicting the characteristic photopeaks of the different elements on the lens surfaces. For the silicon-based materials, balafilcon A (Fig. 1b) and lotrafilcon A (Fig. 1c), the Si 2p photopeaks are clearly discernible along with the more prominent C 1s, O 1s and N 1s features. A weak F 2p photopeak is also observed for lotrafilcon A. For the HEMA-based material, etafilcon A, a small amount of Na can be seen (Fig. 1a). Individual scans of spectral regions of these samples were also collected and analysed. For example, the C 1s spectra shown in Fig. 2 reveal a markedly different shape for these three lens samples due to different amounts of contributing components from different functional groups (and chemical environments). In particular, for lotrafilcon A dried in nitrogen (Fig. 2c), the C 1s band can be deconvoluted into three components: the C=O functionality (α state at 288.1 eV), the C–N and/or C–O functionality (β state at 286.2 eV) and the C–C and/or C–Si functionality (γ state at 284.8 eV).

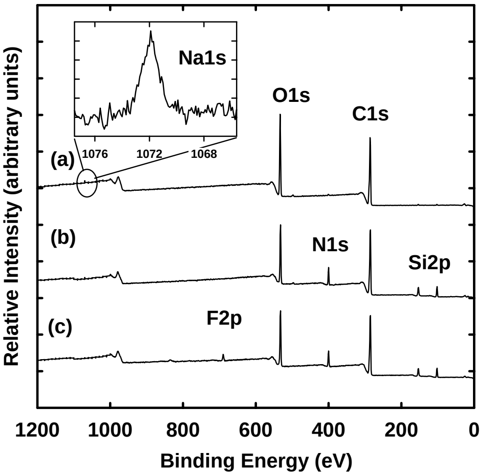


Fig. 1. Survey X-ray photoelectron spectrum for: (a) etafilcon A; (b) balafilcon A; (c) lotrafilcon A (all dried in nitrogen).

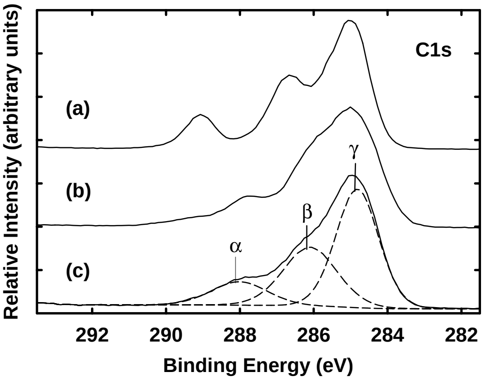


Fig. 2. Comparison of the C 1s envelopes for: (a) etafilcon A; (b) balafilcon A; (c) lotrafilcon A (all dried in nitrogen). C 1s deconvolution for lotrafilcon A, α indicates peak for O=C (288.2–289.6 eV; actual binding energy = 288.1 eV), β indicates peak for C–N and/or C–O (286.4–286.6 eV; actual binding energy = 286.2 eV) and γ indicates peak for C–C, $CH_x$ and/or C–Si (284.5–285.5 eV; actual binding energy = 284.8 eV). The ranges of binding energies listed here were gathered from literature data.

Table 3
Elemental surface composition of soft contact lens materials as determined by XPS[a]

| Category | Material | Elemental composition (at.%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C | O | N | Si | Na | F | P | Other |
| CW | Lotrafilcon A | 66.0 ± 2.8$^*$ | 17.8 ± 1.4$^*$ | 9.5 ± 1.7$^*$ | 5.0 ± 3.1$^*$ | | 1.3 ± 0.8$^*$ | | 0.5 ± 0.3 |
| | Balafilcon A | 65.1 ± 0.2$^*$ | 18.3 ± 0.2$^*$ | 7.3 ± 0.2$^*$ | 9.0 ± 0.2$^*$ | 0.2 ± 0.2 | | | |
| DD | Etafilcon A | 71.0 ± 0.9$^*$<br>(68.2[b] [6],<br>70.6[c] [6],<br>72.5 [10]) | 26.2 ± 0.2$^*$<br>(30.6[b] [6],<br>22[c] [6],<br>27 [10]) | 0.4 ± 0.0<br>(0.4[b] [6],<br>1.2[c] [6],<br>0.4 [10]) | 1.9 ± 1.0<br>(0.2[b] [6],<br>5.6[c] [6],<br>0.1 [10]) | 0.5 ± 0.2$^*$<br>(0.3[b] [6],<br>0.2[c] [6]) | (0.4[c] [6]) | | |
| | Nelfilcon A | 69.5 ± 0.4$^*$ | 28.2 ± 0.3$^*$ | 0.7 ± 0.1$^*$ | 1.6 ± 0.3 | 0.1 ± 0.1 | | | |
| | Hilafilcon A | 80.8 ± 1.8$^*$ | 15.3 ± 1.2$^*$ | 3.1 ± 0.7$^*$ | 0.7 ± 0.2 | | | | |
| | Ocufilcon A | 69.2 ± 1.8$^*$ | 27.6 ± 0.9$^*$ | 0.2 ± 0.1 | 2.0 ± 0.6 | 0.6 ± 0.2 | | | 0.4 ± 0.0 |
| DW | Polymacon | 70.6 ± 1.9$^*$<br>(68.9 [9],<br>69.8[d] [10]) | 27.9 ± 1.1$^*$<br>(24.4 [9],<br>29.8[d] [10]) | (0.25 [9],<br>0.2[d] [10]) | 1.4 ± 0.9<br>(6.4 [9],<br>0.1[d] [10]) | | | | 0.1 ± 0.0 |
| | Omafilcon A | 67.8 ± 1.2$^*$ | 29.5 ± 0.2$^*$ | 0.6 ± 0.1$^*$ | 1.3 ± 1.0 | | | 0.8 ± 0.0$^*$ | |

[a] Experimental values of elemental surface composition (in at.%) of soft contact lens materials dried under nitrogen (normalised values ± standard deviation, $n = 3$, as determined by XPS). Values from literature are provided in parentheses for comparison. Elements in the lens material as expected from the theoretical composition are denoted by an asterisk.

[b] Cast moulded etafilcon A lens.

[c] Lathed etafilcon A lens. Additional lens materials that have been analysed in literature are: bufilcon [9]—66.7 at.% C, 24.6 at.% O, 1.4 at.% N, 2.65 at.% Si, 1.35 at.% S; tefilcon [9]—74.7 at.% C, 24.8 at.% O, 0.1 at.% Si, 0.4 at.% Na; vifilcon [10]—73.5 at.% C, 19.8 at.% O, 6.1 at.% N, 0.1 at.% Si; silicon-based lens with phosphorylcholine coating [7]—63 at.% C, 24.1 at.% O, 3 at.% N, 8.4 at.% Si, 1.5 at.% P; lens material with 98% HEMA and 2% MA [15]—86.4 at.% C, 12.8 at.% O, 0.1 at.% N, 0.1 at.% Si, 0.4 at.% Na, 0.2 at.% Cl; lens material with 70% HEMA and 30% NVP [15]—63 at.% C, 24.1 at.% O, 3.2 at.% N, 0.3 at.% Na.

[d] Surfactant wash of the polymacon lens before analysis.

The surface elemental compositions for the various lens materials dried in nitrogen and similarly analysed are summarised in Table 3. Evidently the values for etafilcon A and polymacon estimated in this study are found to be in good accord with their corresponding published results [6,10], thus validating our methodology. Table 4 compares the carbon functional groups deduced from the deconvolution of the C 1s feature in the HEMA-based etafilcon A and polymacon lenses to that of the theoretical HEMA composition. Evidently, good agreement between experimental results and theory is obtained, which further supports the reliability of the present XPS analysis. Polymacon is the only material for which the functional group composition can be calculated, because it is composed only of the monomer HEMA. Given that etafilcon A is mainly composed of HEMA, the functional group composition can therefore be approximated to that of HEMA.

Table 4
Comparison of the theoretical and experimental elemental composition (at.%) of the carbon functional groups in the HEMA-based lenses: polymacon and etafilcon A (±standard deviation, $n = 9$)

| Material | Functional group | | |
|---|---|---|---|
| | C–C or $CH_x$ | C–O | C=O |
| Polymacon (experimental) | 50.2 ± 2.8 | 37.2 ± 3.1 | 12.6 ± 1.2 |
| Etafilcon A (experimental) | 49.1 ± 3.8 | 38.3 ± 2.4 | 12.6 ± 0.9 |
| HEMA (theoretical) | 50 | 33.3 | 16.7 |

Table 3 also shows that the only difference observed between the present work and the data reported in literature is the N content in polymacon. In the present work, no N was detected in polymacon, which agrees with the expected theoretical content (Table 1) but differs from the 0.2–0.25% N reported in the literature data (Table 3) [9,10]. It should be noted that these reported (literature) values fall within the detection limit of the XPS (0.2%). Table 5 shows that the

Table 5
Balafilcon A: theoretical elemental composition (at.%) of each individual monomer compared to the measured composition.

| Monomer/material | Element | | | | |
|---|---|---|---|---|---|
| | C | O | N | Si | Na |
| TVPC | 60 | 20 | 4 | 16 | |
| NVP | 75 | 12.5 | 12.5 | | |
| NCVE | 54.5 | 36.4 | 9.1 | | |
| PBVC | 53.5 | 25.2 | | 21.3 | |
| Experimental (balafilcon A) | 65.1 ± 0.2 | 18.3 ± 0.2 | 7.3 ± 0.2 | 9.0 ± 0.2 | 0.2 ± 0.2 |

theoretical elemental composition of each individual monomer in balafilcon A are in reasonable accord with the measured composition of balafilcon A. Similarly, all of the other lens materials investigated have surface compositions that are reasonable with respect to the theoretical monomer composition (data not shown).

Fig. 3 summarises the average Si content for individual lens type (Fig. 3a), and the Si content (Fig. 3b) and the average impurity content in different lens materials for the three drying methods (Fig. 3c). Both DD and DW lenses were grouped as the HEMA-based materials and compared to the silicon-based

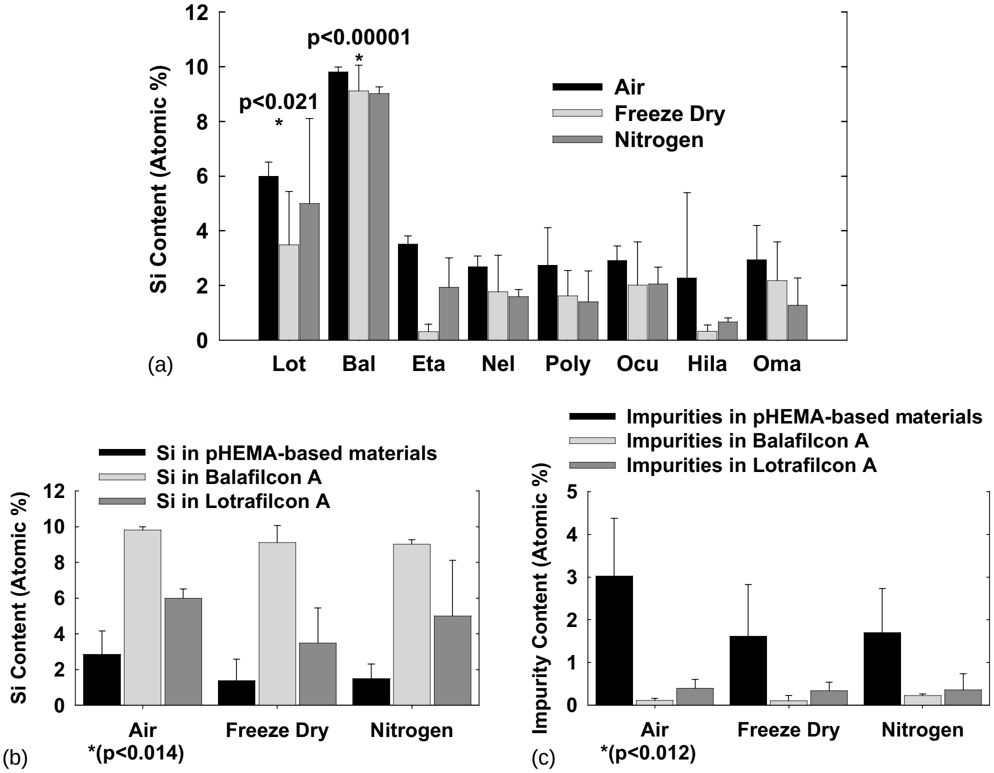


Fig. 3. (a) Comparison of the average Si content (at.%) for eight different lens materials, lotrafilcon A (Lot), balafilcon A (Bal), etafilcon A (Eta), nelfilcon A (Nel), polymacon (Poly), ocufilcon A (Ocu), hilafilcon A (Hila), and omafilcon A (Oma), with three different drying methods. (b) Average Si content (at.%) in balafilcon A (CW), lotrafilcon A (CW) and HEMA-based materials (both DD and DW) for each drying process. (c) Average impurities (Si and other elements) (at.%) in balafilcon A (CW), lotrafilcon A (CW) and HEMA-based lenses (both DD and DW).

CW lenses. As expected, Si was detected on the surface of all materials but at varying concentrations, with the highest concentrations for the silicon-based CW lenses (Fig. 3a). On average (over all three drying techniques), the Si contents of the CW lenses were found to be 4.8 ± 2.2 and 9.3 ± 0.6% on the surface of lotrafilcon A and balafilcon A, respectively, which were significantly ($P < 0.021$) higher than the 1.9 ± 1.3% Si content for the HEMA-based materials (Fig. 3a). The Si contents of balafilcon A and lotrafilcon A were compared with that of the HEMA-based lenses in the three drying processes in Fig. 3b. The drying process did not introduce any statistical difference in the Si content for lotrafilcon A, balafilcon A or HEMA-based lenses. However, an average of the Si content in all the lenses revealed that lenses dried in air had an average of 4.1 ± 2.7%, which was statistically higher ($P < 0.014$) than the average Si-content lenses that were freeze-dried (2.6 ± 2.9%) and dried in nitrogen (2.9 ± 2.9%). The detection of silicon by XPS for contact lens materials that do not theoretically contain Si is not unusual. Silicon has been previously detected on the surface of the HEMA-based lens etafilcon A [6] and was attributed to impurities introduced in the manufacturing process [6,9]. Although silicon-based CW lens materials are expected to have a higher Si content, the silicon surface contamination cannot be distinguished from the Si component of the material by XPS analysis.

The effects of the three drying processes were also evaluated by looking at the total impurities (including Si) on the lens surface. The impurities defined here include any element that was not expected from the theoretical composition of the material (identified in Table 3 with an asterisk). The sum of total impurities for each lens material was used in this analysis. For example, etafilcon A should only have C, O, and Na on the surface, so any Si or other elements were counted as impurities. For lotrafilcon A, the composition was not fully known, but it was assumed based on the available structural information that C, O, Si, N and F were all present. On average, lenses dried in air had a higher amount of total impurities (2.3 ± 1.7%) than freeze-drying (1.3 ± 1.2%) and drying in nitrogen (1.3 ± 1.1%), which was statistically significant ($P < 0.012$). Furthermore, both DD and DW HEMA-based lenses appear to have a higher amount of non-Si impurities than the CW silicon-based materials (Fig. 3c). However, this trend could not be verified because the Si impurities for the silicon-based lenses could not be accounted for.

Based on the present analysis, there is no predominant indicator to suggest that one particular drying technique is far superior to the other two. It is important to note that the surface composition of the materials was not significantly affected by the change in the optical transparency, as in the case of the freeze-dried lenses. Nevertheless, based on the relatively high amount of Si and other surface impurities for lenses dried in air, and the loss of transparency found for freeze-dried lenses, we conclude that drying in nitrogen is the preferred method of sample preparation for XPS analysis of hydrogel lenses. Furthermore, apart from Si and impurities, no general correlation in the surface composition among the three drying techniques is evident. Although there are statistically significant differences between certain elements with certain drying techniques for some of the individual lenses, there is no obvious trend with any one particular drying process.

In the group of the HEMA-based lenses, hilafilcon A is the only lens material with a surface composition that was statistically different from all other HEMA-based lenses. Hilafilcon A is the only material of those studied that is cast moulded and subsequently packaged in the mould. The other HEMA-based materials are cast in separate moulds, extracted in separate vessels and eventually packaged in separate containers. These results are particularly interesting in suggesting that XPS analysis may be able to detect subtle differences in manufacturing processes.

## 4. Concluding remarks

XPS has been used as a fast and powerful method to monitor protein deposition and spoilage on hydrogel lenses, as well as drug interaction with other types of materials [8,10,18]. Given the appropriate drying protocol before analysis, it is feasible to use this technique to monitor chemical interaction on hydrogel contact lenses. In the present work, baseline values of the surface composition were obtained for a range of the more frequently prescribed soft contact lens materials, including two novel CW silicon-based soft materials, four DD and two conventional DW soft HEMA-based lens materials. These baseline values were found to correlate well with the published data [6,9,10] and can be used for future studies on lens interactions with chemicals, pharmaceuticals and tear components, as well as surface modification of contact lens materials. Drying lenses in air introduces more impurities than drying in nitrogen or freeze-drying (despite the lenses become partially opaque with the latter method). Drying the hydrogel contact lens materials in a nitrogen atmosphere would therefore be the preferred sample treatment for any XPS analysis of these soft materials.

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