IL NUOVO CIMENTO **46 C** (2023) 165
DOI 10.1393/ncc/i2023-23165-y

Communications: SIF Congress 2022

# Estimation of contact lens friction coefficient: The need for a protocol

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received 10 February 2023

**Summary.** — Contact lens discomfort (CLD) is a sporadic or frequent condition that affects millions of contact lens users worldwide. The experience of the contact lenses (CLs) wearers is strongly influenced by many factors, among these the physical properties of lens materials. Especially, the friction coefficient (CoF) plays a critical role in the balance between lenses and ocular environment. The aim of our study is to quantify the CoF for different CLs by means of a nano-tribometer. Three experiments were performed following protocols already published in the literature, in order to evaluate the CoF dependance on testing parameters, such as sliding speed, applied normal force and number of sliding cycles. Our results identify a lack in the reproducibility of already published experiments and the necessity to identify a measuring standardized protocol.

## 1. – Introduction

Contact Lenses (CLs) are the most used biocompatible prosthetic devices, essentially employed in ophthalmic medical field for correcting cornea's refractive errors. In recent decades, they have also found wide application in cosmetics, in the prevention of ultraviolet exposure, in ophthalmic treatments and, more recently, in the administration of ocular drugs [1, 2].

The interactions between CLs and eye components induce alterations in the ocular environment balance, which could result in complications related to its wear, such as hypoxia, inflammation, papillary conjunctivitis, allergic or toxic reactions or microbial keratitis [3]. Notwithstanding the rate of some of those complications has been reduced by introducing new materials, including hydrogel (Hy) and silicone-hydrogel (SiHy) [4],

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the Contact Lens Discomfort (CLD) remains the major cause of CL drop-out [5, 6]. Specifically, in the literature it has been reported that the drop-out rate is independent of the hydrogel-based formulation used to manufacture the CLs [7, 8]. Therefore, with the aim to reduce this phenomenon, it is needed to deeply investigate the impact of physical properties of CL materials on the CLD. In fact, the goodness of CL materials is dependent on many parameters from a material science perspective, namely: i) water content and ionicity, ii) dehydration, iii) oxygen transmissibility, iv) mechanical behaviour, v) wettability, vi) friction and vii) deposit of protein and/or impurities. Despite several clinical studies have been performed, the scientific community is still unable to establish a correlation between physical properties of CLs and CLD. This speculation is corroborated by the comparison between the friction of different soft CLs with data of clinical trials on subjective discomfort [9-11].

Unfortunately, quantifying the coefficient of friction (CoF) is not trivial: although several measurement methods have been developed, none of them are able to provide results that are reproducible or comparable to those obtained with similar techniques [12, 13].

In the present work, we reported the estimation of CoF for soft CLs under the influence of the critical experimental parameters by means of a nano-tribometer, following the protocol adopted in published studies, such as the number of sliding cycles, applied normal force, and increasing sliding velocity. Our results compared with the correspondent similar studies suggest poor reproducibility and highlight the necessity to optimize a standard, accurate and replicable protocol to obtain CoF.

## 2. – Materials and methods

Tribological tests were performed on nelfilcon-A, delefilcon-A, omafilcon-B and HEMA-MMA-GMA CLs; table I summarizes the main technical parameters of of the used samples. All experiments were carried out by means of NTR3 nano-tribometer (Anton Paar TriTec SA, Austria). The measurements were performed by a glass disk (5-mm diameter) fixed at the free end of a HR-S 314 cantilever (Anton Paar TriTec SA, Austria), which have a nominal stiffness equal to 0.0479 mN/m and 0.1559 mN/m for normal and lateral forces, respectively. The CLs were placed on a polyoxymethylene

Table I. – *Technical parameters of CLs samples employed in this work, namely Food and Drug Administration (FDA) group, Equilibrium Water Content (EWC), Oxygen permeability (Dk) ($(cm^2/s)mlO_2/(ml \cdot mmHg)$), Central Thickness (Ct) (mm), Base Curve (BC) (mm), Optical Spherical Power (OPS) (dp).*

| Sample | FDA | EWC | Dk | Ct | BC | OPS |
|---|---|---|---|---|---|---|
| nelfilcon-A | 2 | 69% | 26 | 0.1 | 8.7 | −15 to −0.50 +0.50 to +8 (0.50D steps over −6) |
| delefilcon-A | 5 | 33% core, ≥80% surface | 140 | 0.09 | 8.5 | −0.50 to −6.00; +0.50 to 6.00; +6.50 to −12.00 (0.50D steps) |
| omafilcon-B | 2 | 65% | 34 | 0.07 | 8.7 | +8.00 to −12.00 |
| HEMA-MMA-GMA | 4 | 55% | 16 | 0.08 | 8.7 | +8.00 to −12.00 |

(POM) spherical base having a curvature radius comparable to that of the CLs. This base was blocked within a cylindrical cell made of anodized aluminium, which allowed containing liquids. A top cover on POM held the CLs in their position thanks to three magnetic pins. The conducted experiments can be distinguished in three types:

I) nelfilcon-A was tested under respectively 2 mN and 5 mN using a sliding speed of 0.1 mm/s for 30 sliding cycles in dry conditions. The amplitude of sliding was 0.5 mm and the tests were performed without any lubricant. Before changing the applied load, the lens was hydrated by a buffered solution (pH 7.2) (Universale Plus Soluzione Unica, Schalcon, Italy). CoF measurements were performed on five samples to evaluate variations in terms of sliding cycles and applied load;

II) delefilcon-A CLs were tested in full immersion condition of borate buffered solution (BBS, Unisol®, Alcon, Fort Worth, TX). Five samples were investigated under ten loads sequentially rising from 0.1 mN to 2 mN, sliding at speed of 0.2 mm/s; the path analysed was 0.7 mm and 25 cycles were performed for every load. CoF was obtained as a slope of the $F_\mathrm{T}/F_\mathrm{N}$ curve for two ranges of values (from 0.1 to 1 mN and from 1 to 2 mN). $F_\mathrm{T}$ and $F_\mathrm{N}$ were derived by a mean on 25 cycles for every load considering 20% of the cycle track;

III) in the last experiment, nelfilcon-A, delefilcon-A, omafilcon-B and HEMA-MMA-GMA CLs were compared under the same testing conditions. Five tests for sample were performed in full immersion condition of a buffered solution (pH 7.2) (Universale Plus Soluzione Unica, Schalcon, Italy), applying a constant load of 5 mN and sliding speeds rising from 0.05 mm/s to 4 mm/s.

The friction value was obtained as

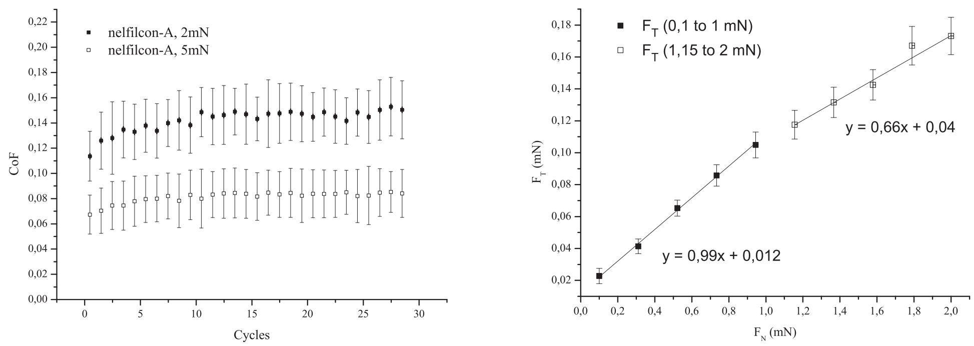
$$\mathrm{CoF} = \frac{\langle F_\mathrm{L}^{+}\rangle + \langle F_\mathrm{L}^{-}\rangle}{2\langle F_\mathrm{N}^{+}\rangle}, \tag{1}$$

where $F_\mathrm{L}^{+}$ and $F_\mathrm{L}^{-}$ represent the lateral force in the direct and reverse direction, respectively. The estimation was carried out considering the 90% of the running track, in order to remove the boundary effects due to direction reversal.

## 3. – Results and discussion

Our study was motivated by the need to identify a standard protocol for estimating the CoF. In this aim, we have evaluated the weight of some test parameters on the estimation of the CLs friction. Specifically, the impact of applied loads and sliding speeds were quantified by means of three different experiments:

I) To study the dependence of CoF for CLs on applied load, five tests were carried out on five unworn nelfilcon-A following the experimental protocol proposed by Roba *et al.* [14], *i.e.*, using applied normal forces equal to 2 mN and 5 mN, and 0.1 mm/s sliding speed of probe. By plotting the obtained CoF mean values as a function of the number of cycles (fig. 1(a)), it was evident how our results appeared ∼80% lower than those obtained by Roba *et al.* (0.344–0.474) [14]. Furthermore, our findings showed that the CoF mean values decreased in correspondence to the higher value of applied loading force (fig. 1(a)). A similar trend was obtained on SiHy CLs as reported by Zhou *et al.* [15].




(a) (b)

Fig. 1. – (a) Measurements of Coefficient of Friction (CoF) for nelfilcon-A samples. The values were plotted as a function of number of sliding cycles for two different applied forces, namely 2 mN and 5 mN. (b) CoF values obtained as a slope of curves $F_{\mathrm{T}}$ *vs.* $F_{\mathrm{N}}$ for two ranges of load, namely (0.1–1) mN and (1.15–2) mN. Each test was performed five times and data were reported as mean value ± SD.

Unfortunately, the CoF dependence of hydrogel-based CLs to the load still remains unclear: the scientific literature available is thus quite broad, even though characterized by a certain data inconsistency [15-18], reporting both the increasing and decreasing trend of the CoF value with respect to the load. For example, Dunn *et al.* [18] reported an opposite trend respect to our data; the authors justified the increment of CoF due to a higher applied force as consequence of the polymer surfaces collapse resulting in the water content loss.

II) Following the experimental protocol used by Dunn *et al.* [18], we have investigated the behaviour of delefilcon-A CLs under increasing load, in particular using the nominal force ranges: (0.1–1) mN and (1.15–2) mN.

Despite using the same experimental conditions, the CoF values obtained (fig. 1(b)) were not only quite different, but also discordant with the increasing trend reported by Dunn and colleagues [18]; in fact, the fits performed showed a reduction in slope from lower to higher loads, which means a lower CoF for higher applied normal forces.

In addition to the applied normal forces, sliding velocity is also a critical parameter in CoF determination [19-21]; therefore, the CoF values obtained under a single constant speed condition are not significant [14, 21, 22].

However, it is not possible to establish an unambiguous relationship between the sliding speed and CoF. For example, Qin *et al.* [19] observed a CoF decreasing in correspondence to higher sliding velocity; this trend appears dependent to the lubricant and unrelated to different hydrogel-based formulation. In contrast, a well-defined physical dependence was not obtained by Samsom *et al.* [20], studying the CoF value with respect to different velocity (0.3–30 mm/s).

III) The need to evaluate the CoF behaviour as a function of the sliding velocity has justified the third experiment aimed to compare CoF of four CLs (nelfilcon-A, delefilcon-A, omafilcon-B and HEMA-MMA-GMA) under increasing sliding speeds. In detail, all experiments were performed using the same applied load (5 mN), in accordance to what has been used by Roba *et al.* [14]; for each single sliding speed, ranging from 0, 05 mm/s to 4 mm/s, CoF values were obtained as a mean on 30 cycles (fig. 2).

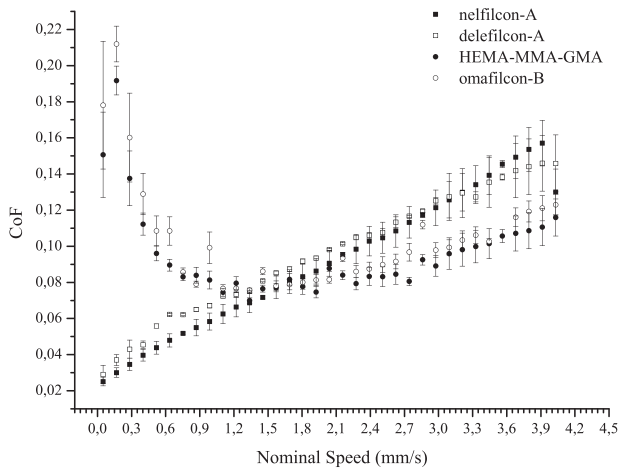



Fig. 2. – CoF measurements performed for nelfilcon-A, delefilcon-A, HEMA-MMA-GMA and omafilcon-B CLs, obtained using a normal force of 5 mN and a sliding speed ranging from 0.05 to 4 mm/s. Each measurement was performed five times and plotted as mean ± SD.

The nelfilcon-A and delefilcon-A exhibited a similar behaviour despite the differences in their materials (Hy the first one, SiHy the second one). At the same time, omafilcon-B and HEMA-MMA-GMA, both Hy-types, exhibited an opposite trend compared to nelfilcon-A, at least for lower speeds. Trends for nelfilcon-A and delefilcon-A are more likely descriptive of an eyelid-corneal blinking process, where the lower CoF measured at lower velocities could be induced from surface treatments effect, such as the presence of surface brushes [23] sometimes grown on CLs surfaces to increase wettability or reduce biofouling [24, 25]. HEMA-MMA-GMA was stored in buffered solution containing hyaluronate and HPMC, which could affect CoF at lower speeds as shown in the study by Qin *et al.* [19]. Unfortunately, this speculation did not justify the different trend observed omafilcon-B, whose store solution is enriched with wetting agents, such as HPMC and MPC polymers.

The results obtained in our studies were reproducible; however, the goodness of experimental procedures could not yet be standardized.

## 4. – Conclusions

Nowadays, the studies reported in the scientifical literature show that the CoF of the CLs can be directly associated with CLD. Unfortunately, these studies follow non-standardized protocols and the results are often not reproducible, as demonstrated in this work. In detail, we have demonstrated the irreproducibility of the main protocols reported in the literature, probably due to the strict interconnection among the testing parameters and the CoF value. Therefore, it is required a standardized protocol which takes into account both the physiological mechanisms of the eye and the physical parameters (*i.e.*, sliding speed, normal force, number of cycles, lubricant, etc.) involved in the CoF measurements.

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