· Letter to the Editor ·

Feasibility of smart intraocular lens

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Dear Editor,

Wearable biosensors are monitoring implantable devices that provide real-time detection of biomarkers by means of non-invasive measurements[1]. There is a high demand for novel sensors that can be comfortably used by the patients for clinical monitoring of ocular diseases. Transducers implanted into eyes have been improved and they have the capacity to monitor parameters such as intraocular pressure (IOP), and also have the possibility of recording lactic acid, glucose or cortisol levels[2-3].

Recent advances in miniaturized integrated circuits, biosensors, and wireless power transfer devices have opened new possibilities for intraocular implantable biomedical systems[3]. Replacing the crystalline lens of the human eye with an artificial intraocular lens (IOL) is a very common procedure in ophthalmic practice. An IOL is made from silicone or acrylic with several shapes, usually composed of two elements known as optic (the central area responsible for refraction) and haptics (appendages that hold the IOL in place; Figure 1A). New IOL technologies are currently being developed, among them those including microelectronic sensors[4].

Currently, there are available near-field connection (NFC) mini tags that allow transferring data between the tag and a smartphone in wireless mode. The purpose of the experiment described here was to find out if communication between a conventional smartphone and a mini tag placed intraocular is possible. The simple experiment I describe here clearly shows that communicating a conventional smartphone with one of such devices inside of an eye is possible.

For this, I carried out the following procedure. A mini NFC tag was bought from the e-commerce company Amazon. The tag was a flat disk, 8 mm in diameter, with a central integrated electronic chip of about 1 mm in size surrounded by a spiral antenna (Figure 1B). A pig's eye was mounted on a dummy face, and the tag was placed inside the eye, in the same position as the IOL is placed in a cataract surgery procedure (Figure 1C). Next, by using the NFC-Tools app (available from Google Play) installed on a conventional smart phone, I was able to read and write on the tag (Figure 1D). The screen captures of this app shown in Figure 1E-1F show the tag technical specifications and also the sentence "Hello!! This is your lens implant!!" (outlined in red) used for testing. This sentence was first written in the tag while it was inside the eye, and then it was read back from the tag, using in both cases the app mentioned above. This procedure was repeated with several eyes without any problem.

Integrated circuits and antennas similar to those used in these tags can be embedded in the haptics of an IOL without significantly changing its shape and size and without interfering with the optic area of the lens. Moreover, capsular rings, commonly used in combination with IOL, may also function as antennas and include microelectronic devices. These integrated circuits may include microsensors that sense parameters such as IOP, which can be read by the patient by simply approaching a smartphone with an appropriate app to his/her eye. High IOP is considered a leading risk factor for glaucoma[5], one of the main causes of blindness. The data produced by devices such as the one described here could be used, for instance, to adjust the appropriate dose of glaucoma drugs or to test new drugs. Similarly, chemical sensors could detect glucose levels, which could be useful for preventing diabetic retinopathy. After implantation, using suitable sensors and smartphone apps, these devices could be useful to adjust drugs dosage, test new drugs, or even prevent diabetic retinopathy. It is easy to imagine endless possibilities for improving such implantable devices. In the near future, they could significantly be improved, complement cataract surgery, have a positive impact on eye care, and contribute to reduce patient follow up consultation cost[6].

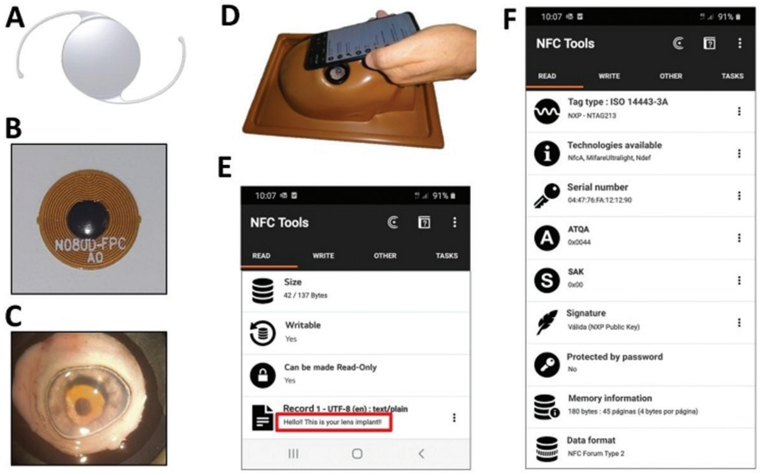

Figure 1 Testing procedure of intraocular mini NFC tag A: IOL showing the central optic component and the haptics; B: Mini NFC tag used in the procedure described here; C: NFC placed inside of a pig's eye; D: Smartphone writing and reading the NFC tag; E and F: Screen captures of the NFC Tools app. IOL: Intraocular lens; NFC: Near-field connection.

Here, I present a "proof of concept" (POC), and therefore the experiment and results should be regarded as an early stage research that demonstrates the feasibility of intelligent IOLs, showing that this idea can come to fruition and work in a practical sense. POC in medical devices serves to provide evidence that the device can effectively perform its intended functions. This stage is crucial to assess the viability of the concept prior to a full-scale development. In order to implement a prototype of such IOL described here, further experiments are needed to gather data to fully prove its reliability, stability and biological safety. *In vitro* cytotoxicity, ocular inflammation, and IOP fluctuations must be tested[7]. Since the materials currently used to manufacture IOLs are safe and suited to completely embed integrated circuits, long time stability and biological safety can be achieved.

A further advantage of intelligent implantable devices is that the data they produce may be analyzed by using artificial intelligence (AI). Ophthalmology is one of the most active clinical specialty in using AI[8-9]. There are AI models applicable to diabetic retinopathy, age-related macular degeneration, retinopathy of prematurity, glaucoma, and anterior segment disorders[10] that will allow AI-assisted clinical decision-making, personalized treatment, virtual medical and nursing assistance, and target drug development. The machine learning component of AI uses huge data samples to train its models to detect patterns or rules that can be applied to new data to make predictions or discern features[8]. Since it is possible to communicate the IOL device with a conventional smartphone, it is possible to collect large amounts of data useful for AI applications. Moreover, the combination of telemedicine and AI may be a solution for healthcare providers worldwide[11].

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