New testing methods in Beauty, new trends and innovative solutions to evaluate in vivo cosmetics efficacy: a technological panorama of nomad and connected diagnostic devices

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1. Introduction

In 2025, the beauty industry is evolving significantly in an increasingly connected, digitalized, personalized world where social networks and influencers impact the beauty routines of new generations of consumers. In response to the expectations of these new consumers, who are more inclusive, eco-responsible and attentive to scientific evidence, cosmetic brands are combining traditional products with a personalization of their offer accompanied by essential product recommendations. The emergence of personalization dates to the 2000's. It came from consumer expectations and the ability of brands to offer tailor-made products such as foundations in the 2010's and adaptation to different shades of complexion. With the advent of digital technologies, the miniaturization of measurement tools and data analysis, this "personalization" of cosmetic care is reaching sophistication thanks to the development of nomadic and connected diagnostic devices. These diagnostic devices allow consumers to access products that meet their exact care concerns, their skin type, their performance needs (moisturizing, sebum-regulating, etc.) but also the context of use (heat, humidity, etc.). This personalized diagnosis is based on high-tech digital evaluation tools, complex data processing and is very often supplemented by consumers' self-assessment. In these major advances in personalization and beyond optical and physico-chemical measurement technologies, AI plays a leading role in processing complex data and training algorithms from thousands of face photos on the recognition of skin signs Materials and Methods
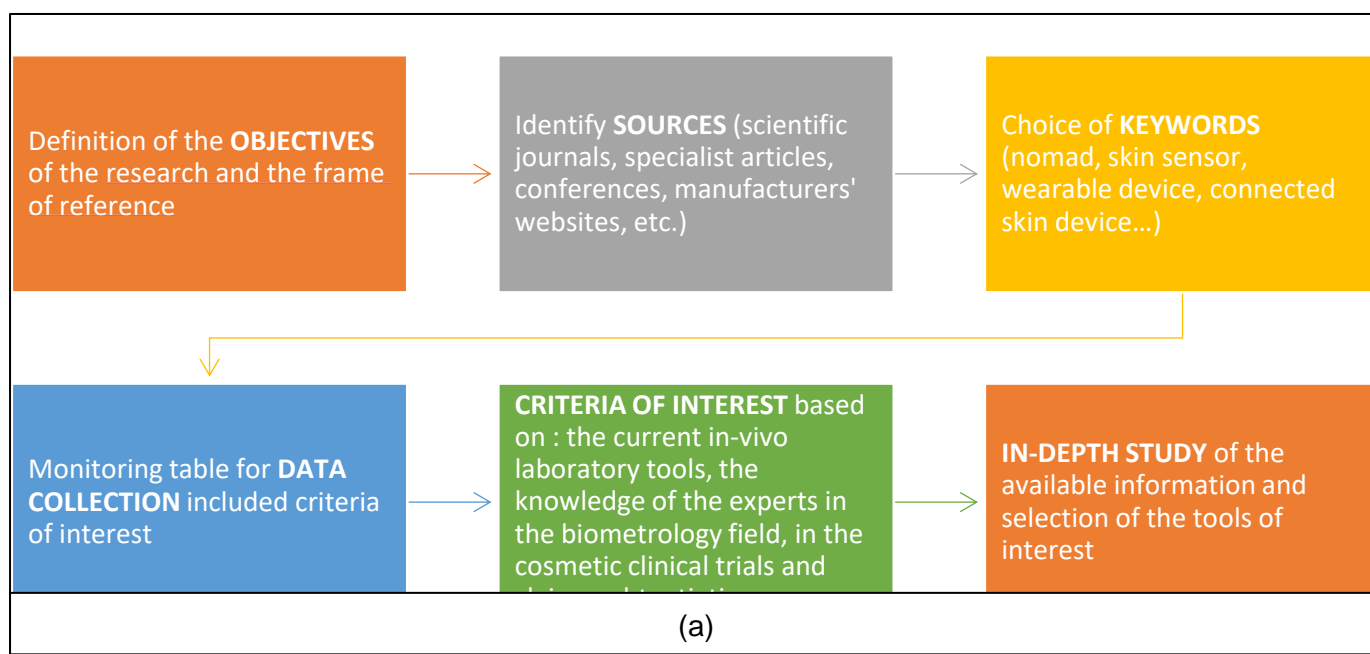
Glossary:

Terms	Definition
Biomarkers	Biological indicators to evaluate physiological or pathological processes, or responses to a treatment (inflammatory molecules, enzymes, or proteins)
Conductivity	Ability of the skin or a substance in contact with it to conduct electric current.
Electrochemistry	Chemical processes that involve the movement of electrons, particularly in reactions at the interface of electrodes and electrolytes (ions, metabolites, or other biomarkers through skin-contact electrodes).
Image analysis	Process of examining, processing, and interpreting visual data (typically acquired through imaging technologies)
Mechanical	Measurement by deformation system of mechanical properties such as elasticity or firmness

Multispectral imaging	Imaging technique that captures image data at multiple wavelengths across the electromagnetic spectrum…
Patch	Flexible or rigid device applied to the skin, containing sensors or active compounds
Skin sensor	Probes designed to detect and measure specific physical parameters of the skin or physiological signals emitted by the skin. (e.g., moisturizing, sebum)
Spectroscopy	Measurement of the interaction between electromagnetic radiation and matter to identify and quantify molecular composition (e.g., Raman, NIR, FTIR)
Trackers	Wearable devices that continuously monitor and record physiological or behavioral data

All the research was carried out online.

Inspired by the PRISMA methodology [1] (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), the research was carried out according to the following schedule (figure 1 a) and is iterative.

Figure 1. a) Main stages of research

Definition of the **OBJECTIVES** of the research and the frame of reference

Identify **SOURCES** (scientific journals, specialist articles, conferences, manufacturers' websites, etc.)

Choice of **KEYWORDS** (nomad, skin sensor, wearable device, connected skin device…)

Monitoring table for **DATA COLLECTION** included criteria of interest

CRITERIA OF INTEREST based on : the current in-vivo laboratory tools, the knowledge of the experts in the biometrology field, in the cosmetic clinical trials and

IN-DEPTH STUDY of the available information and selection of the tools of interest

(a)

Appropriate keywords (table 1) are essentials for the research:

Table 1. List of Keywords

Keywords	
Mobile	Skin device
Nomad	Connected skin device
Patch	Wearable skin analyzer
Skin analyzer	Portable skin device
Skin sensor	Wireless skin device
Skin diagnostic	Skin analysis
and all other keyword combinations	

The sources selected should not be more than 7 years old, as this is a fast-changing market and information can quickly become obsolete.

Guiding Logic and Comparative Framework

Our approach was structured around a comparative analysis between home-use devices and measurement tools used in Contract Research Organization. This comparison aimed to assess the performance, reliability, and usability of home devices in comparison to the gold-standard instruments typically employed in cosmetics in vivo testing laboratories.
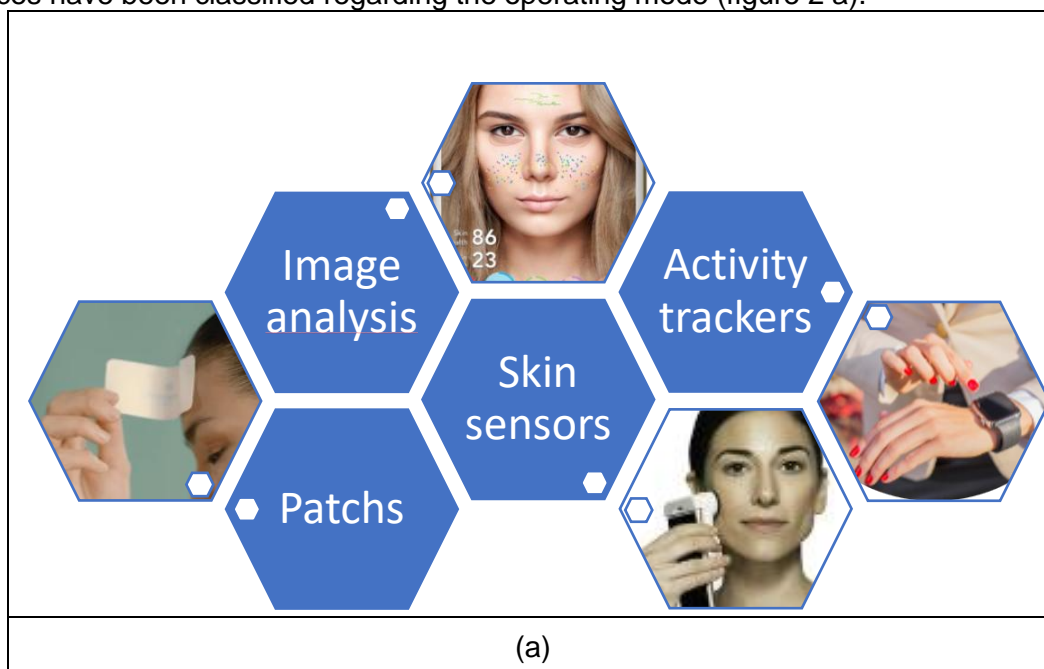
Criteria Selection

The selection of evaluation criteria was informed by three main pillars:

- **Our hands-on experience** with both consumer and laboratory-grade tools.
- **State-of-the-art practices** observed in established in vivo cosmetic testing laboratories.
- **Our scientific expertise** in the field of cosmetics allowed for a critical and informed perspective when assessing the relevance and validity of each criterion.

Limitations

It is important to note that a number of criteria could not be evaluated due to the lack of access to specific measurement instruments. This limitation necessarily constrained the scope of our analysis.

The devices have been classified regarding the operating mode (figure 2 a).

(a)

Figure 2. a) Type of technologies

For each category, several criteria need to be considered (figure 3 a):

Operating mode

Technical characteristics

Measured parameters

Influencing factors management

Credibility of available information

Accuracy, Repetability and Reproductibility

Connectivity
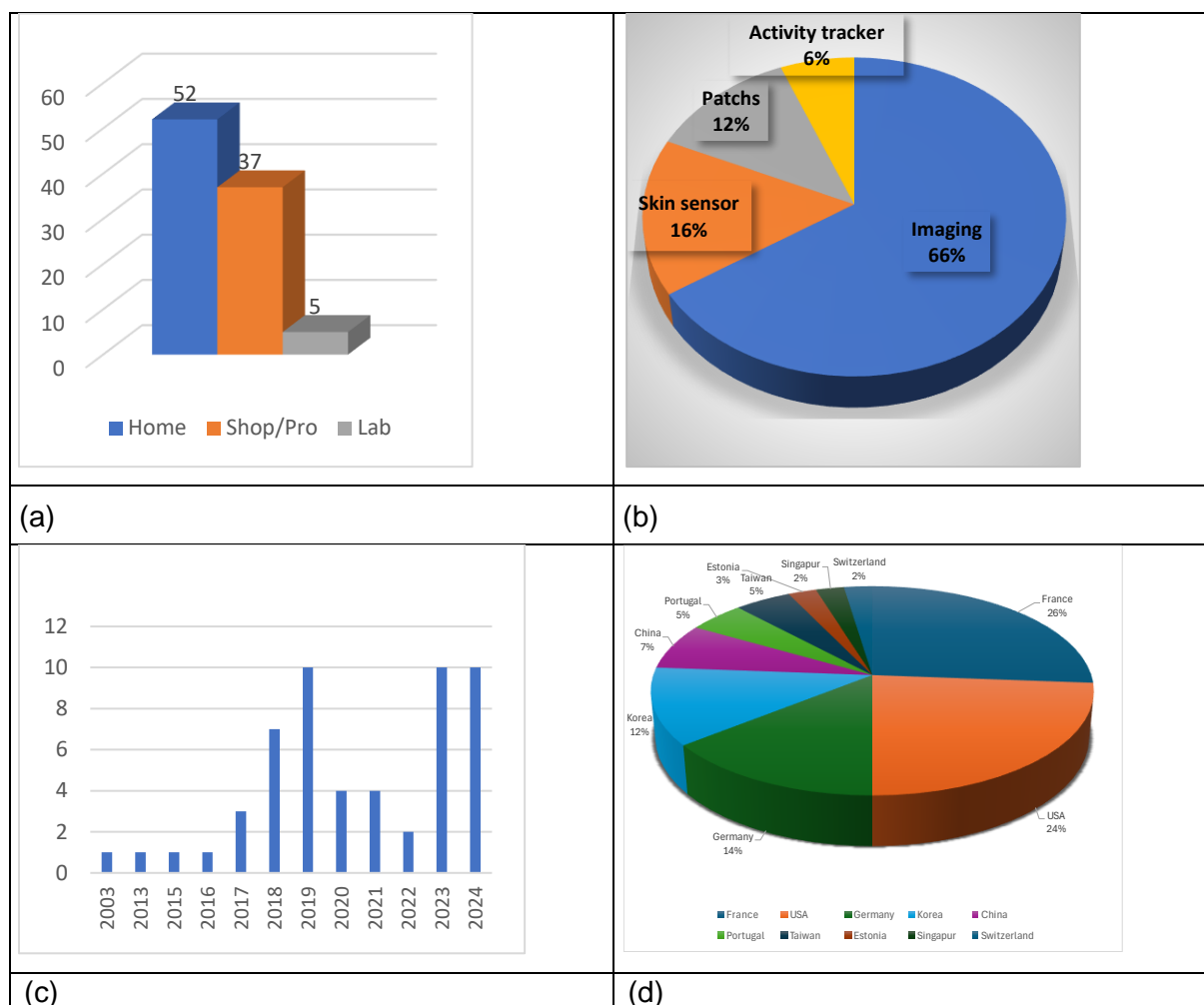
Data management

Home use facility

(a)

Figure 3. a) check-list of parameters considered

This worldwide overview does not take into account of all parameters above as technical characteristics and information about Accuracy, Repeatability and Reproducibility, as these data are difficult to access for some tools.

Our research method allowed us to identify a lot of potential home-devices but after an in-depth study of each of them, many are ineligible.
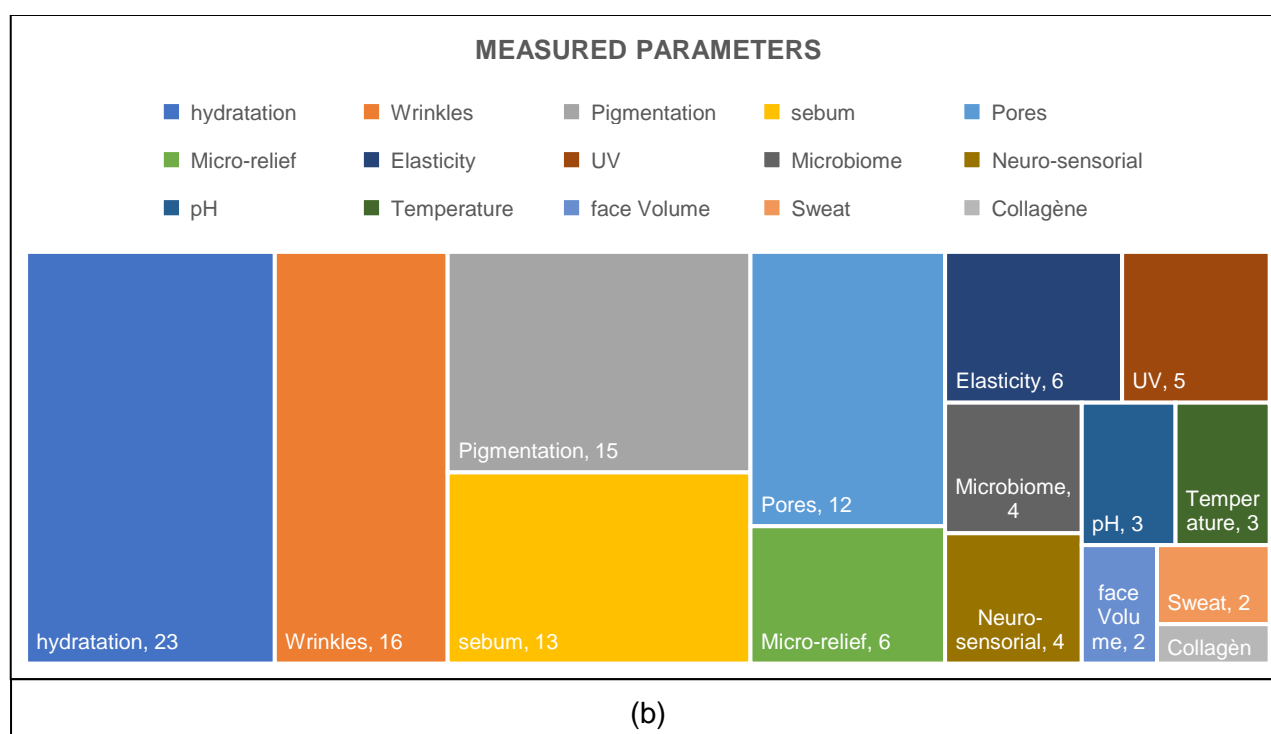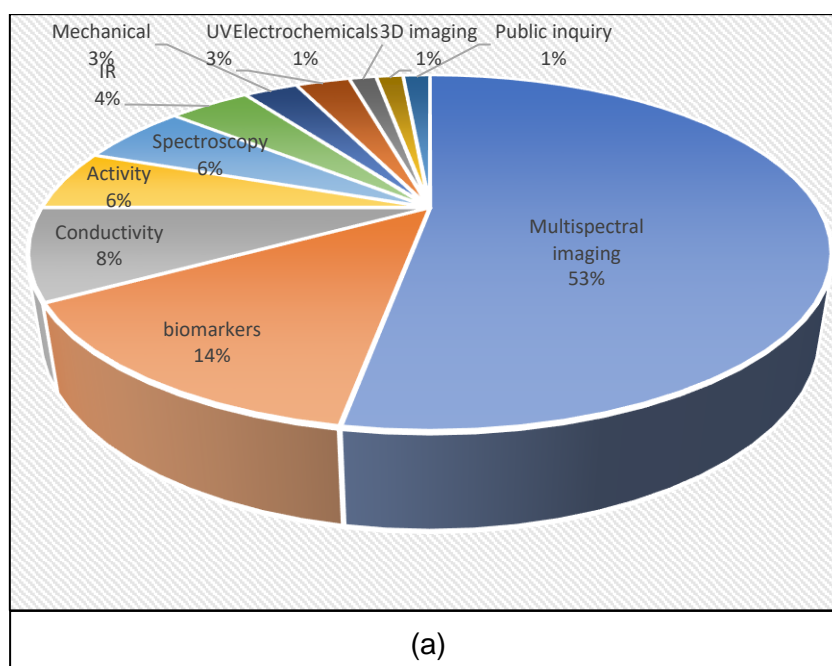
3. Results

More than 80 systems and devices were identified to be potentially so called "nomad device" using the general criteria and key words described in methods. 52 are home devices, 37 could be used as shop or pro devices, 5 are used as lab systems (figure 4 a). Considering data acquisition techniques, 66% are based on imaging device, in which 40% use Smartphones camera, 19% are exclusively using IOS and 7% are specific imaging devices (figure 4 b). 16% use contact skin sensors, 12% are based on patches and 6% are activity tracker like, Watch, wristband, clothing.

Figure 4. a) System and device category; b) System and device type; c) Nb of device by Launching date; d) Nb of device by Country

Regarding their development we looked on their launching date and country of origin. Development started in 2003 but mostly after 2013 with a first rise up to 2019 where the Covid 19 stopped the development until 2023 where it raised up strongly again since (figure 4 c). Most of the device were developed in France, USA, Germany, Korea, China, Portugal, Taiwan, Estonia, Singapore and Switzerland (figure 4 d).
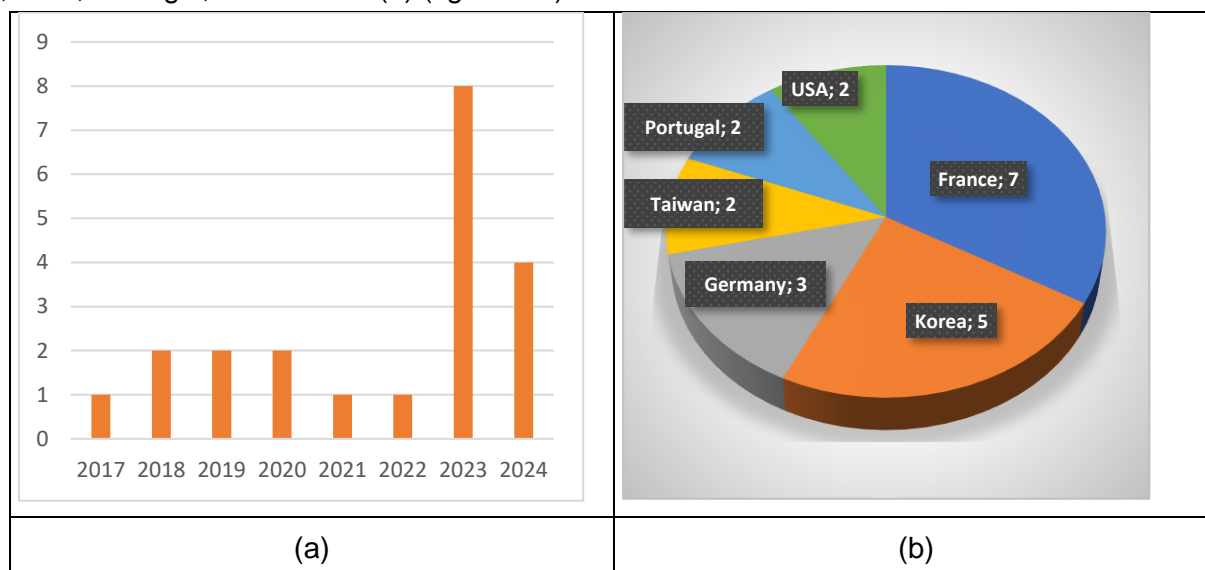
Next, we analyze the technology used by the devices (figure 5 a) and the measured parameters. Main technology using camera from smartphones, relates to color imaging which is classify in multispectral imaging (53%) as it uses the 3 channels red, green and blue, sometimes combined with specific illumination like daylight, UV, IR and other specific skin sensors. More than one parameter could be measured by this technology like micro-relief, wrinkles, pores, pigmentation, skin colour and brightness, uniformity and up to 30 different parameters, some announcements give extreme numbers up to 200. Next technologies founded were Biomarkers (14%) using mainly patches for microbiome, protein, free radicals; Conductivity using electric conductance (8%) for hydration, sebum and sweat; Heart activity (6%) for neuro-sensorial; Spectroscopy (6%) for pigmentation, skin phototype, colour and collagen. There is also some specific techniques like Mechanical (3%) for elasticity, IR thermal (4%) for environment or skin temperature, Electrochemistry for pH, sweat. Some devices can combine several technologies in one device.

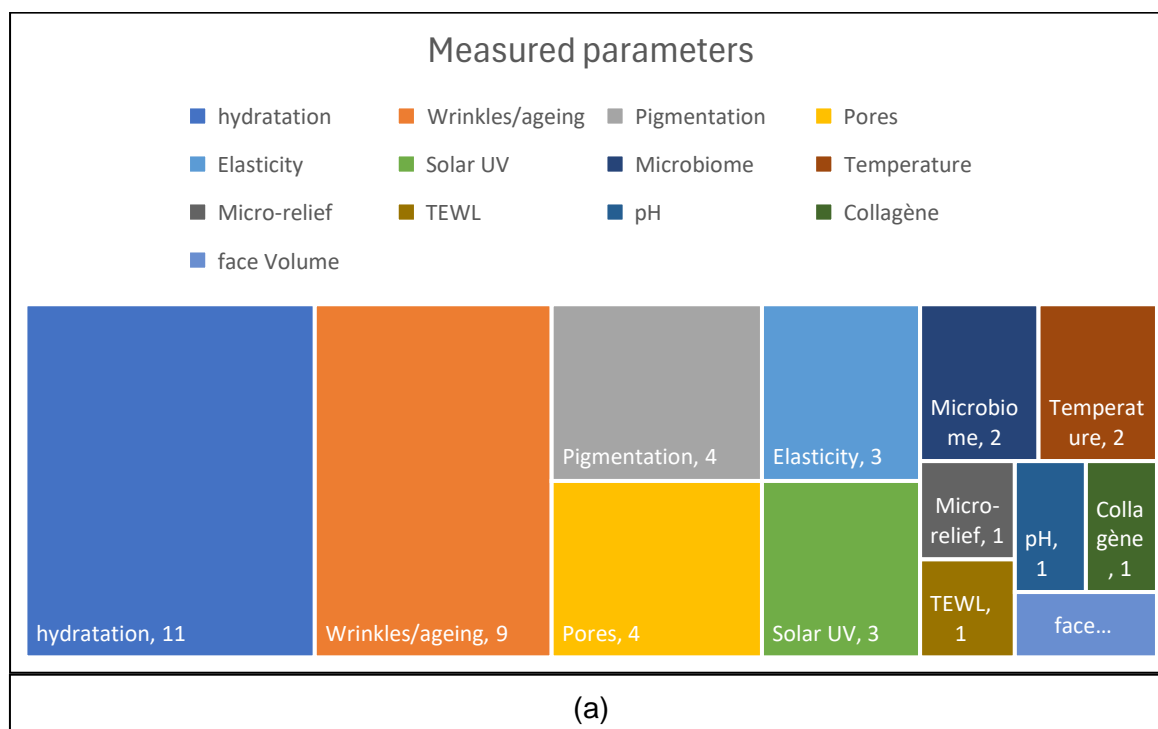**Figure 5.** a) technologies used in devices b) Measured parameters

The measured parameters (figure 5 b) are split in physical and biological parameters for skin. There are also devices to measure your environment like UV, temperature, humidity and measure your activity like steps, levels, rest an sleep time. We remain oriented on skin care and ageing applications. Hydration, sebum, sweat and microbiome are the functional parameters of the skin while wrinkles, elasticity, pigmentation, collagen are ageing factors and sebum, pores, UV, and temperature belong to skin care.

After we made the selection of the devices using our objective criterias, 21 remains. They were launched between 2017 and 2024 (figure 6 a), coming in majority from France (7), Korea (5), Germany (3), USA, Portugal, and Taiwan (2) (figure 6 b).

Figure 6. a) launching date of the selection; b) Country of origin of the selection

Four technologies remain from the selection , mainly Multispectral imaging (11) based on smartphones (7) or specific camera (4), Specific skin sensors (10) coupled with smartphones for data processing as well and Biomarkers (2), last is activity tracker (1). Three devices combine more than one technology to produce more parameters.

Figure 7. a) measured parameters in the selection

Regarding measured parameters (figure 7 b), most of them are kept in the selection as some devices can still measure more than one parameter as they combine technologies like imaging and sensors or detect more using different illumination.

2. Discussion

The importance of home devices (52 out of 80) can be interpreted as a consequence of the maturity of the connected objects market in general [2] and consequence of the proficiency of Generation Z consumers, as well as those from Generations X and Y, in utilizing such devices, akin to smartwatches [3]. 5 home devices from test laboratories is a relatively small number that illustrates the need for a rigorous, standardized, and scientific approach to biometrological studies conducted in vivo on humans. Instrumentation manufacturers typically aim for features that rarely consider connectivity, speed, agility but accuracy and reproducibility for measurements on a limited number of subjects (20-30) conducted under at least controlled environmental conditions including in lighting, temperature, and humidity.

The analysis of the technological aspect of connected diagnostic devices shows a predominance of image measurement. Beyond the fact that imaging the surface of the skin or hair provides the opportunity for a multiparametric diagnostic already well-recognized by testing stakeholders, it remains that access to this measurement is largely attributable to the widespread use of smartphones today. This question of employing cameras as the primary means of assessing skin condition under typical home-use scenarios by non-specialist individuals raises questions concerning the reliability of these measurements. Indeed, we are far from the standardized environmental conditions that represent the rule of laboratories in the acquisition of data on subjects with control of lighting, light environment, temperature and humidity. The quality and variety of lenses employed by smartphones in these mobile measurements also raise questions about the robustness of the results obtained when compared to the cameras and visualization tools used in laboratory settings.

This optical measurement also raises the question of how these images are processed by the media applications used, 60% of which are based on phone applications. It can be observed that the conditions of acquisition, the acquisition itself as a dependent subject and the processing of the data show a fragility of this measure. For these connected devices to be employed by large-scale testing laboratories, it will be technologically imperative to qualify the characteristics of the lenses, as well as the algorithms used for image processing and the interpretations derived therefrom. Transparent validation by CROs necessitates raw data retrieval. However, raw image ownership by app developers complicates access, as transmission hinges on individual device manufacturers' policies. Reproducibility and precision tests will be essential for their adoption by laboratories. On the other hand, the utilization of biomarkers through the analysis of skin or hair samples originates primarily from the medical domain, with their reliability hinging largely on the quality of collection tools and the analytical processes employed. The collection of skin samples has been conducted for over 25 years by stakeholders in the testing sector, using methods such as swabbing or stripping, particularly for microbiota analysis. The conductivity, spectroscopy and biomechanical technologies of these nomadic and connected devices are based on measurement technologies that have been used routinely for more than 30 years in measuring instruments in test laboratories. The parallel with classical measurements is all the easier when it comes to their interpretation and the evaluation of their veracity.

Finally, it should be noted that some of the technologies presented do not directly concern the diagnosis of the skin but allow the measurement of the environment, (UV, temperature) for a part of them and for another part the characterization of neurosensory [4] parameters such as cardiac

activity. It is important to note that all technologies combined, all the measured parameters offered by these nomadic tools are similar to those studied by laboratories today: micro-relief, wrinkles, pores, pigmentation, skin color and brightness, uniformity, microbiome, protein, free radicals, hydration [5], sebum, sweat, pH [6], pigmentation, skin phototype, color and collagen. The parameters assessed by these new tools are in line with the well-established claims of the beauty industry, such as the study of moisturizing, anti-aging, and sebum-regulating effects, which constitute the current "golden" claims. While the measured parameters remain the same, these devices will expand the scope of claims to include allegations directly related to consumers' lifestyles and real-life conditions.

3. Conclusion

It seems important to note that the parameters of mobile connected tools are the same as those traditionally used in laboratories until this study carried out in August 2024. Will we be able to see in the near future the appearance of new parameters that are more "medical", more "social", in line with new dermo-cosmetic trends and the references of influencers in digital networks? Testing laboratories can remain the reference for these novel applications and the guarantors of objective and scientific evaluation of product effects on a larger scale. AI plays an essential role in data processing via algorithms that need to be known and evaluated so that this essential part of measurement processing does not remain confined to a black box of data. It is interesting to discuss the subject of self-assessment questionnaires offered in association with these connected skin or hair diagnostics. It should be noted that it was difficult for us to evaluate them one by one since we would have had to test them all live and analyze the questions in their number and content and also measure the impact of the answers on the diagnostic results.

In addition, concerns arise regarding sensitive skin health data management and its preservation across diverse global regions. Within Europe, GDPR mandates stringent data protection protocols, ensuring privacy and imposing rigorous organizational obligations. Non-EU diagnostic tools' compliance remains uncertain.

It should be noted that the raw image, outside of the filters applied - to reduce noise and ensure optimal quality - is owned by the developers of smartphone apps and that the transmission of these raw images depends on each manufacturer of these devices. In addition, in the use of these mobile devices, whatever they may be, it will be relevant to include the capture of environmental parameters (temperature, humidity, altitude, lighting, UV, etc.).

Following the discussions on the panorama offered by these tools, we propose to examine what the orientations may be for future research. We can discuss and imagine two main lines of development. The first, the easiest in the short term, would be the development of diagnostics using smartphones and the possible adaptation of spectroscopy technologies to standardize lighting and improve results. The second way of developing these connected tools used at home may be based on existing and future medical technologies. This approach can focus on data collection via probes equipped with specific technologies for instantaneous measurement of impedance, fluid, and gas, as well as through patches that collect skin samples. The biomarkers from these samples can subsequently be analyzed (or not) using omics methods. These two paths of development are the most likely, but one cannot help but imagine the existence of a futuristic connected mirror to which the cosmetics consumer will connect in his bathroom to make a complete diagnosis of the conditions of his skin and hair.

Contract Research Organizations (CROs) will represent one of the actors in the validation of these tools and provide crucial endorsement for their future widespread adoption in a scientific context, beyond mere commercial and marketing considerations. Without a high level of expertise and structured guidance through training and conversational robots, these nomadic diagnostic tools will remain mere gadgets, lacking reliable interpretation and utility for the R&D efforts of brands. The latest developments in neurosensory measurements of subjects' emotional parameters will enable a variety of combined studies, much like the infinite array of biomarkers that can serve as indicators of physical, chemical, and physiological changes in the skin and its appendages.

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