Review Article

Future challenges of direct-to-consumer genetic testing for sustainable safety in the Republic of Korea's skin care market: a systematic review

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Background: Social distancing due to the pandemic is accelerating the fragmentation of Korean society in the megatrend of continuous individualization after industrialization. In this context, consumers are turning to direct-to-consumer (DTC) genetic testing for tailored skin healthcare strategies. However, there are still concerns about the safety of personal information in DTC genetic testing. The purpose of this review article is to examine the sustainable safety of DTC genetic testing for customized dermatology products, focusing on skin healthcare market after coronavirus disease 2019 (COVID-19).

Methods: A systematic review approach was used in this study. Using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow chart, a total of 920 references were selected from PubMed, Medline, and Scopus. The composition of a total of 59 references from professional papers was finally reviewed. To this end, the most relevant recent literature was added, and the reference period was limited to 2018 to 2023 based on a 6-year period.

Results: With the practice of mask wearing since COVID-19, various methods are being used to strengthen the skin's immune system, and maintain and promote skin health. There is a need to have a method to increase the safety of DTC genetic testing for sustainable skin healthcare market.

Conclusions: It is concluded that there is a need to continue to develop more sustainable and safer security applications (apps) in the field of customized dermatology cosmetics to address the privacy issues and improve the accuracy of DTC genetic testing.

Keywords: Consumer; sustainable and safe; customized dermatological cosmetics; direct-to-consumer genetic testing (DTC genetic testing); security application

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Introduction

At the end of 2019, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) first appeared in humans, causing a global catastrophe called the coronavirus disease 2019 (COVID-19) pandemic (1). SARS-CoV-2 spreads around the world, infecting people, and changing the ways we interact with others all over the world. Many governments have worked hard to control the spread of the disease. Despite the introduction of public health measures, the infection persists. It is predicted that such diseases and epidemics will continue in the future. The worldwide spread of SARS-CoV-2 has led to the development of rapid diagnostic tools. Still, there is no end in sight. It has even been foretold that we will have to live with these diseases continuously in the future (2,3). According to the circumstances of the times, non-face-to-face communication has continued in recent years. We provide an overview and classification of health applications (apps) currently available on the market to combat COVID-19 (3). Most of the apps have been provided by government or national authorities, indicating that these apps play an essential role as public health crisis management tools. By engaging most of the population in personal health self-tracking and providing self-diagnostic technologies, these apps are considered a key driver of participatory approaches to control the spread of COVID-19. Social distancing measures have been put in place due to the COVID-19 pandemic, forcing many people to stay indoors, suspend daily outdoor activities, and limit face-to-face social interactions with friends, colleagues, and family (4,5).

Accordingly, studies on COVID-19 and sustainable skin health are being conducted from various angles. The epidermis is the first line of defense against infection. A deregulated action against exogenous pathogens can activate T cell responses in atopic dermatitis, ichthyosis suppurative, and vitiligo (6). SARS-CoV-2 is transmitted through interaction with contaminated surfaces with the inhalation of droplets and can be fatal to humans. With the passage of time, the interest and meaning of health and well-being and continuous safety is expanding. Aristotle said that he saw health as an effort toward a physical, mental, and spiritual state in which life flourished. In modern times, the definition of health should focus on the coexistence of disease and disability with well-being, along with continued safety (7).

In addition, from this skin health point of view, the use of augmented reality (AR) is expected to play a more prominent role for customized cosmetics and dermatology. Furthermore, since it provides an experience like reality in a state that is not separated from reality, it makes customized cosmetics possible with the consideration of variables, which enables consumers to check skin texture, pores, and moisture content, and provide help accordingly (8). Recent research suggests that opportunities for tele-dermatology (TD) in mobile health will include improving quality of service, streamlining health care processes, reducing costs, and providing more accessible care (9). Through this, we foresee that the integration of artificial intelligence (AI) and AR with the use of wearable sensors are expected in future developments. As the demand for customized cosmetics continues, a new market for dermatology is expected to open (9,10). However, the customized cosmetics that consumers take on site poses several safety issues. Systematic management of such safety issues is necessary (11). Direct-to-consumer (DTC) genetic testing is a genetic test that consumers can directly receive through an institution specializing in genetic testing without visiting a medical institution for checking on specific genes, e.g., *Nrf2* gene. With the forecast that the global genetic testing market will grow at a high rate of more than 10% annually, the DTC genetic testing market is also expected to grow. The need for DTC genetic testing is spreading worldwide, but in Korea's DTC genetic testing market, the market is not properly formed due to multiple regulations and insufficient legislation. A significant number of DTC genetic testing

Highlight box

Key findings

- This study suggests the potential for the development of direct-to-consumer (DTC) genetic testing for sustainable skin healthcare market post-coronavirus disease 2019.

What is known and what is new?

- In previous studies, several research has been conducted on customized cosmetics and customized inner beauty products with DTC genetic testing for skin healthcare.
- However, there has been no prior research suggesting improvement measures to address concerns about personal information leakage regarding DTC genetic testing. Sharing genetic test results is a core clinical health behavior in genomic medicine.

What is the implication, and what should change now?

- With the development of DTC genetic testing for personalized skin care services, there is a need to develop security apps for protecting personal genetic information and maintaining sustainable safety in the field.

patients wish to have genetic testing done outside the scope of general healthcare providers (12). In addition, this industry is expanding with more genes and additional information to handle. Nevertheless, ongoing concerns about the quality of DTC genetic testing, the psycho-social impact, and privacy remain unresolved. After COVID-19, personalized products appear even more rapidly through the era of super-individualism named as the nano society. Customized marketing that maximizes individual needs, such as the need for personalized products, is being actively developed. Customized cosmetics are developing in various ways in another type of niche market. Accordingly, it should be regarded as an industry that creates high added value (12,13).

Therefore, this study explores how social distancing due to the pandemic is accelerating the fragmentation of Korean society in the megatrend of continuous personalization after industrialization. In this context, consumers are turning to DTC genetic testing for tailored skin healthcare strategies. However, there are still concerns about the safety of personal information in DTC genetic testing. The purpose of this review is to examine DTC genetic testing for sustainable safety for customized dermatological cosmetics products, focusing on skin healthcare after COVID-19. We present this article in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting checklist (available at https://mhealth.amegroups.com/article/view/10.21037/mhealth-23-61/rc).

Methods

Search strategy

This is a systematic review. We searched PubMed, Medline, Scopus using the following search term chains following the PRISMA flow diagram guidelines: COVID-19; sustainable and safe; customized dermatological cosmetics; DTC genetic testing; security application. *Figure 1* shows the flow chart involved in the process of finding and selecting studies for inclusion in this systematic review. In addition, the research model diagram is summarized in *Figure 2*. Among the 920 retrieved papers, 333 duplicated records were deleted and 518 were excluded. There were 63 unrelated topics, 207 off-topic documents, and 248 documents that differed from the main text. Additionally, the 11 papers excluded from the original text included 4 references that could not be cited, 4 references of which the original text that could not be confirmed, and 3 with which the original text could not be confirmed. Accordingly, 59 final items consisting of reviews (n=24), studies (n=21), experiments (n=11), reports (n=2), systematic reviews, and meta-analysis guidelines (n=1) were included (14).

Eligibility criteria

Inclusion criteria for this review were as follows: (I) COVID-19; (II) sustainability and safety; (III) customized dermatological cosmetics; (IV) DTC genetic testing; (V) security application studies or DTC genetic testing in dermatology dealing with sustainable safety for customized dermatological cosmetics.

Screening and data extraction

We considered various paper types such as original research papers, review papers, internet papers, brief reports, and series. Publication dates were limited to the last 6 years, from 2018 to 2023. Inability to access the full text, full text not including raw data, inappropriate topics, university dissertations and dissertations, and not related to the focus of the review were excluded.

Results

Strengthening skin immunity and increasing awareness of skin health problems caused by COVID-19

The COVID-19 pandemic has become a serious problem causing major physical, mental, and social problems around the world. In addition, the lives of many people around the world are threatened, and as a result, concerns about their health are emerging. Compared to β-CoV generations and severe acute respiratory syndrome (SARS) in the past, SARS-CoV-2 is highly contagious and more lethal (15). As we enter the long-COVID era, research on the relationship between COVID-19 and the skin is being conducted from various angles (16). There is a growing awareness of the safety of products for healthy skin, such as the importance of sustainable cosmetic perfumes (17), which have been attracting attention since the emergence of COVID-19 (16-18). This is because the sensitivity to oxidative stress increases accordingly. Restoring physiological immune homeostasis in healthy individuals has become a very important research topic in recent years (9). In this way, the desire for skin healthcare is leading to eco-friendly products and safe ingredients. In a study conducted in Vietnam on

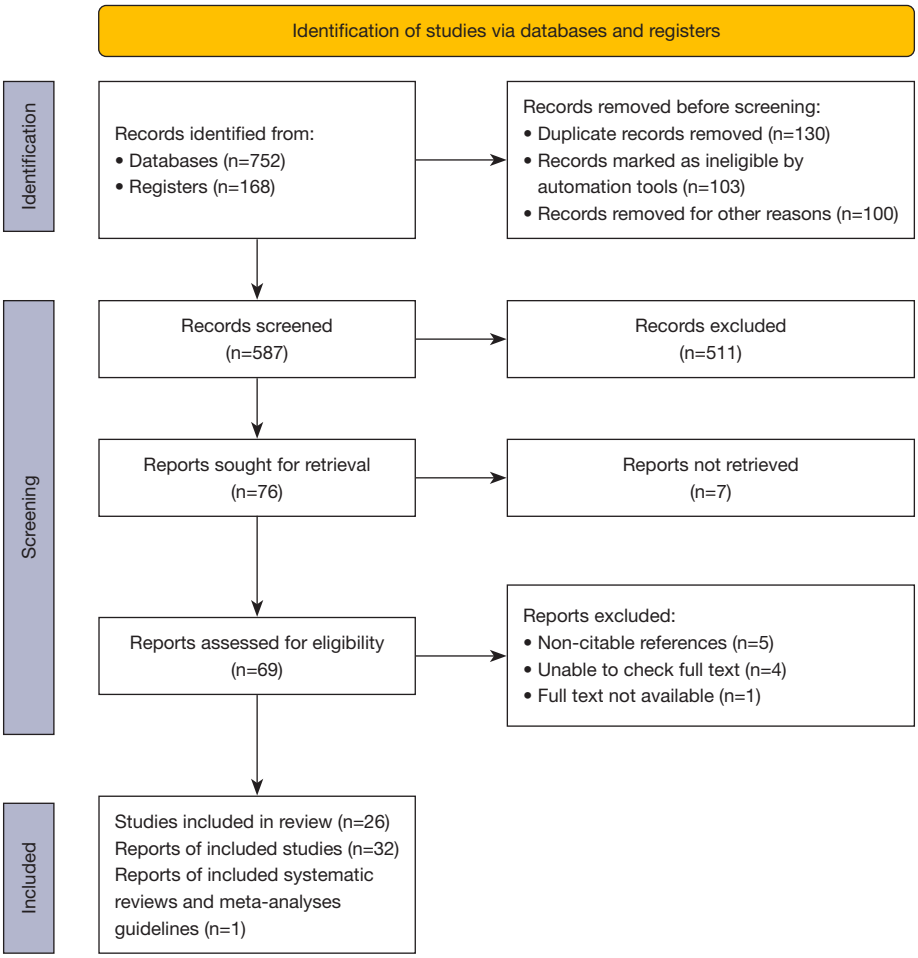

Figure 1 PRISMA flowchart. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses.

young female consumers' purchase intentions for eco-friendly cosmetics, it was found that attitudes and subjective norms according to knowledge and motivation related to green cosmetics were highly correlated with purchase intentions of green cosmetics (19). It is predicted that consumers' awareness of skin healthcare and the demand for products will continue to increase (16,17).

Customized skin healthcare through DTC genetic testing

The public interest in genetics is increasing, as it has recently moved into a personalized and nano society. This is driving the rapid growth of DTC genetic testing. The future paradigm of this industry will gradually shift to a consumer-oriented genetic testing model. As the non-face to face society continues, patients conduct their own tests. They ask their healthcare providers for specific genetic tests and then pass the results back to researchers for examination (20). DTC genetic testing can provide individual with clearer access to new information about individual ancestral traits and health. In this new post pandemic era, consumers turn to social media for help and discussion. YouTube is the largest social media platform for to general public to access to genetic testing videos, which provides a wealth of DTC genetic testing related videos. Through this, individual can quickly and easily search for genetic information. However, there are still many controversies. The effectiveness of these tests and their impact on individual and people's knowledge and cognition need to be further studied. Nonetheless, it will become increasingly common for consumers to do direct genetic testing with the help of the Internet. In this context, the impact of DTC genetic testing on consumers' health awareness and behavior is emerging as a new concern (21). In Korea, the market for genetic analysis services and DTC

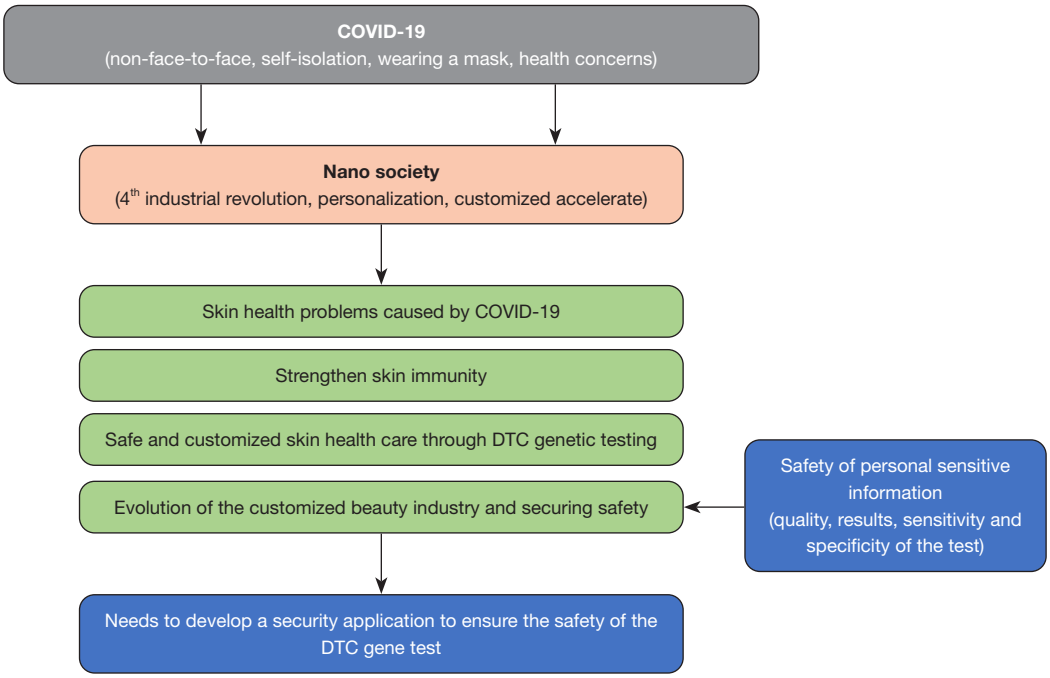

Figure 2 A systematic review possible model. COVID-19, coronavirus disease 2019; DTC, direct-to-consumer.

products has been opened since June 2016. In Korea, DTC genetic testing is used to treat skin aging, stretch marks, acne, and freckles. The goal is to analyze medical-related genes and health. In addition, research on customized cosmetics is also being conducted through an antioxidant mechanism called nuclear factor erythroid 2 related factor 2 (NRF2) through DTC genetic testing. It was confirmed from the point of view of experimental design. Consumers can easily do everything from simple test application via mobile or internet to actual sample collection and submission. Genetic test kit products developed based on customer experience will continue to spread further. This allows raw data to be used for efficient and popular personal genetic testing (22). Research on mobile phone applications for personal health records is being done. One study explored whether the quality of healthcare of individuals receiving treatment in such an environment was improved. Consumers make use of mobile personal health record (mPHR) app or study of two behavioral health to get routine care. In the study, a secure mPHR app diagnosed intervention group participants. It also provided key information on drugs and laboratory test values. These tests al-lowed participants to track their health goals. The use of the mPHR app showed statistically significant results for an individual's quality of care (23). *Table 1* summarizes the customized skin health management research involving DTC genetic testing (13,21-25). As seen from *Table 1*, it was confirmed that the 4th industrial revolution-based convergence medical device has appeared in the global DTC genetic testing market, which has developed customized inner beauty products and customized cosmetics apps with DTC genetic testing since the COVID-19 pandemic (22-24). It is reported that this new cosmetic delivery system has tremendous potential as a next-generation smart carrier system (22,23). Accordingly, it is considered that a new market for customized inner beauty products and customized cosmetics would open. Additionally, randomization of mobile personal health records for behavioral health homes was conducted. It was said that the development of a test mobile app for personal health would be necessary, but DTC genetic testing was found to be controversial even though the Korean government is considering expanding DTC genetic testing (26). Nevertheless, it was confirmed that the DTC genetic testing market is expected to gradually expand (13,21-26).

Evolution of customized beauty industry and securing safety

Consumers today prefer personalized care products that

Table 1 Customized dermatological cosmetics and skin health through DTC genetic testing

Title	Discussion	Author	Journal name	Reference
Development of customized inner beauty products and customized cosmetics apps according to the use of NRF2 through DTC genetic testing after the COVID-19 pandemic	It was confirmed that convergence medical devices based on the 4th industrial revolution appeared in the global DTC genetic testing market. It is expected to be an important data for the development of antioxidants as NRF2 regulators for customized inner beauty products and customized cosmetics	Lee J, Kwon KH. [2022]	*J Cosmet Dermatol*	(22)
Randomized trial of a mobile personal health record for behavioral health homes	App development for mobile personal health is necessary	Druss *et al.* [2020]	*Psychiatr Serv*	(23)
DTC genetic test for customized cosmetics in COVID-19 pandemic: Focused on women in their 40s and 60s in Seoul, Republic of Korea	In the unexplored post-COVID-19 era, it was intended to study the recognition and purchase behavior of customized inner beauty and customized cosmetics through DTC genetic testing. As a result, it was much more effective to use customized inner beauty and customized cosmetics after DTC genetic testing	Lee J, Kwon KH. [2021]	*J Cosmet Dermatol*	(24)
Direct-to-consumer genetic testing	DTC genetic testing is a controversial issue although Korean Government is considering expanding DTC genetic testing. Preventing the exaggeration and abusing of DTC genetic testing is an important task considering the early history of DTC genetic testing in Korea. Nevertheless, the DTC genetic testing market will gradually expand	Kim JW. [2019]	*Genomics Inform*	(25)
Direct-to-consumer genetic testing: Value and risk	DTC genetic testing is spreading, and consumers' needs for it are increasing recently	Majumder MA *et al.* [2021]	*Annu Rev Med*	(13)
Direct-to-Consumer Genetic Testing on social media: Topic Modeling and Sentiment Analysis of YouTube Users' Comments	As DTC genetic testing enables responsible access to new information about ancestry, traits, or health, consumers often turn to social media for help and discussion. YouTube, the largest social media platform for videos, provides a wealth of DTC genetic testing related videos and checks health care resulting from it	Toussaint PA *et al.* [2022]	*JMIR Infodemiology*	(21)

DTC, direct-to-consumer; NRF2, nuclear factor erythroid 2-related factor 2; COVID-19, coronavirus disease 2019.

offer more benefits with minimal effort. The skin delivery of cosmetics has an important effect on the action of cosmetics. Accordingly, many cosmetic manufacturers are focusing on cosmetic delivery. It is said to be innovative with the development of the 4th industrial revolution. New formulas developed in line with these trends are developed with a focus on beauty and inner beauty. New launches of these differentiated and highly functional products are expected. Meanwhile, it also brings safety concerns and tailoring of national laws and regulations (24,27). In March 2020, the customized cosmetic system of the Food and Drug Administration was implemented, and the customized cosmetic dispensing manager qualification system was instigated. Korea's customized industry, led by a customized cosmetic dispensing manager, has been newly opened. The custom cosmetics business still has problems with raw materials, quality, reliability, stability, and safety. However, consumers are increasingly demanding customized cosmetics. By combining sales in small quantities according to individual needs, consumer demand and consequent new demand are expected to increase further. In this study, it was found that the consumption of customized inner beauty formulations and the use of customized cosmetics could be more effective. Based on the above meaningful research results, it is said that in the global DTC genetic testing market, the effect can be in-creased by using customized inner beauty products and customized cosmetics together (25,27). The global impact of COVID-19 has severely impacted health and livelihoods in every country or region, especially in terms of physical consumption behavior. Grooming is an essential physical consumption activity. Because products are personalized to everyone by default,

Table 2 Evolution of customized dermatological cosmetics industry and securing safety

Title	Discussion	Author	Journal name	Reference
A popularization of curation service for dermatological condition in Republic of Korea	Consumers in modern society and advanced consumer culture are in an era where individuality and value are valued, and 'customized products', that is, customized marketing strategies, are being actively deployed throughout the industry. Recently, IT technology that can support personalized services such as artificial intelligence, ubiquitous systems, and marketing automation directly or indirectly affects the distribution industry, which is influenced by individual consumption culture, and its potential is recognized	Park E, Kwon KH. [2022]	*J Cosmet Dermatol*	(12)
An application of AR in cosmetological industry after coronavirus disease-19 pandemic	The consumption pattern in the beauty Industry has been changed due to the COVID-19 crisis. As hygiene issues were raised, non-face-to-face communication was emphasized, and within this framework, the use of AR emerged as one of the hottest topics in the industry	Seo YJ, Kwon KH. [2022]	*J Cosmet Dermatol*	(8)
Risk factors influencing contamination of customized cosmetics made on-the-spot: Evidence from the national pilot project for public health	Custom cosmetics made by consumers or sellers on site have various safety issues, so preventive safety management is required	Kim HW *et al.* [2020]	*Sci Rep*	(11)
Medical photographs: Time saving and data security thanks to a dedicated application	In plastic surgery, personal information about clinical pictures raises data security concerns. The Pixacare software suite is designed to meet these needs in complete security	Kuster *et al.* [2021]	*Ann Chir Plast Esthet*	(31)
Future perspective safe cosmetics: Focused on associated with ISO Natural Organic Index	In the long COVID era, customers in the beauty and cosmetics market will have to apply ISO natural organic ingredients to the cosmetics and beauty industry, reflecting consumer demand for edible ingredients for safety issues. Therefore, it will be able to provide new strategy and implications for a safer cosmetic market that values health and beauty	Lee J, Kwon KH. [2022]	*J Cosmet Dermatol*	(17)
Consumers' lack of understanding of customized cosmetics made on the spot and implications for regulations and controls	Indicated that consumers thought it was important to manage the facility/equipment and safety of raw materials (19.7%, each). We believe this study provides a valuable resource for understanding consumers' perceptions and requirements on customized cosmetics, which contributes to establishing future regulations and guidelines	Kim HW *et al.* [2021]	*Regul Toxicol Pharmacol*	(27)

IT, information technology; AR, augmented reality; COVID-19, coronavirus disease 2019; ISO, International Organization for Standardization.

consumers will in the future choose brands that offer personalized services or experiences (28). This will play an important role in health, especially in the beauty space designed to look different on an individual basis (28,29). It provides a 3D image of the hairstyle and a volumetric analysis of the space occupied by the hairstyle (27,30). The device that measures the shininess of hair is also recognizable and innovative. It also measures and processes hairstyles and colors (31-33). In this way, personalization is evolving into diversity that links health and beauty (26,27). However, DTC genetic testing continues to unresolve ongoing concerns about testing quality issues, psychosocial implications and integration with medical practice, and impact on the health care system (27,30,34). *Table 2* shows studies on the evolution of the customized beauty industry and securing safety (8,11,12,17,27,31). *Table 2* highlights the popularization of skin disease curation services in the customized industry and the modern society's

consumers and advanced consumer culture. It also showed that 'customized products', or customized marketing strategies, are being actively developed through-out the industry (8,12). Recently, information technologies that can support personalized services such as AI, ubiquitous systems, and marketing automation are being recognized for their potential by directly and indirectly influencing the distribution industry, which is influenced by individual consumption culture (11). However, customized cosmetics made on-site by consumers or sellers have various safety issues, so preventive safety management is necessary. Time saving and data security with the applications in plastic surgery, and personal information about clinical photos raise data security issues (29,31). Therefore, it will be possible to suggest new strategies and implications for a safer cosmetics market that values health and beauty. Therefore, efforts should be made to ensure the evolution and safety of the customized skin cosmetics industry (35).

Growth and challenges in the DTC genetic market

The recent web based mobile medical interventions are common (36). They operate with various types of behavior-based tools and treatments provided through the internet and mobile platforms (37). This has accelerated as the rapid transition to a non-face-to-face society has occurred. New proposals are being made for patients and healthcare providers, including utilizing electronic tools, and this can be seen in the significant development of eHealth. The recent introduction of Web 3.0 technology has led to its widespread adoption (38). This is the birth of a personal health application platform (36-38). Therefore, the development of novel technology is a new beginning and strategy in customized cosmetics and customized inner beauty that links sustainable health and safety. This can also be supported by research on purchasing customized cosmetics using hands-on apps that introduce new technologies such as AR and virtual reality (VR). AR is being applied to the beauty industry after the coronavirus disease-19 pandemic. The COVID-19 crisis has changed consumption patterns in the beauty industry (8,12). Likewise, as technology advances, the demand for genetic counseling services is also increasing due to the increased use of direct to consume genetic testing (4,39). As hygiene issues are concerned, non-face-to-face communication is emphasized, and within this framework, the use of AR has emerged as the hottest topic in the industry (8,12). Most people perceive that it will be useful with the use of mobile shopping in the "non-contact" post-COVID-19 era. These results are interpreted as positive perceptions of the potential for development, such as expectations for a systematic system that can diagnose skin and give recommendations when shopping for customized cosmetics via mobile phone (4,40). With the advent of this "non-contact" era, non-face-to-face mobile shopping for customized cosmetics is also increasing. Research results have shown that the possibilities of developing customized cosmetics through mobile shopping in the "non-contact" post-COVID-19 era are limitless. Therefore, the global genetic testing market will grow more and more (4). *Table 3* summarizes global's genetic testing market growth (4). In addition, items allowed for DTC genetic testing in Korea are summarized in *Table 4* (4,40). As such, the customized cosmetics and genetic testing market will grow gradually in the future (4,40).

However, in these developments, the problem of personal information protection, which is a constant concern in DTC genetic testing, which gives the advantage of convenience, should be solved. *Table 5* shows the problems related to personal information leakage of DTC genetic testing for institutions that have websites open among 48 non-medical genetic testing institutions in Korea (41). As such, DTC genetic testing is a genetic test performed in such a way that consumers directly order and receive test results through the Internet. In these inspections, privacy and safety are important issues. Comprehensive and detailed guidelines for this will need to be developed (41). This can become a more serious social problem in the nano society that is becoming hyper personalized (13,26). Therefore, future-oriented values and risks related to DTC genetic testing are proposed for application security enhancement development (13,26,34). Across the globe, research is being done on extended security through the rapid and widespread adoption of Internet of Medical Things (IoMT) (30). This is a significant advance in terms of applications and technologies. These studies show that security measures are integrated with the technology. It also shows that the adoption of secure IoMT applications is possible. The development of these new IoMT technologies, combined with AI, big data, and blockchain, provides new solutions that are more viable than in the past. In recent plastic surgery, medical photos provide medical record information (31). This personal information is essential for security. Smartphones have become the preferred tool for collecting these photos. However, it raises data security concerns. One study found that this

Table 3 Global genetic testing market growth

Country	Current situation	Participating companies	Service field
USA	Initially, all DTC genetic testing services other than wellness items were banned, but the permitted range of genetic testing gradually expanded	AncestryDNA	Provides personal trait genetic testing services including items such as heart rate recovery, lactose intolerance, vitamin D, and endurance
		23andMe	Provides DTC genetic testing services to analyze an individual's DNA. The test reports could show personalized genetic reports from ancestry composition to traits to genetic health risks, such as reports of skin pigmentation, BRCA1/BRCA2 selected variants, and late-onset Alzheimer's disease
Europe	More than 80% of laboratories conducting genetic testing in Europe, such as the UK, Germany and Italy, are affiliated with this organization. EMQN evaluates the precision of various genetic tests, such as genetic mutation tests to diagnose genetic diseases such as muscular dystrophy and Wilson's disease, and molecular pathology tests for target treatments such as BRAF and EGFR	Genetic Health (UK)	Obesity, nutrition, and aging-related DTC genetic testing services
		Bio Logis (Germany)	Comprehensive genetic analysis service including nutrition, drug, carrier, and disease
		Laboratory GENOMA (Italy)	Fetal genetic testing, drug response genetic testing, genetic nutrition testing, risk testing such as cancer/disease
Japan	In the case of Japan's Yahoo, in cooperation with Gene Quest, genetic testing services were provided for about 300 items (110 items related to health risks, 180 items related to constitution and ancestry analysis, etc.)	Genesis Healthcare	About 360 items, including disease risk, ancestry, obesity, skin aging, sports, personality, constitution, and social skills
		Yahoo! JAPAN & Gene Quest	About 300 items, including disease risk, constitution, response to food, major blood tests, personality traits, ancestry, etc.
		MYCODE	It provides analysis results on the risk of various diseases such as cancer risk, colitis, esophagitis, chronic kidney disease, dilated cardiomyopathy, and high blood pressure, as well as physical examinations such as obesity, hair loss, and alcoholism
Korea	Companies participating in the personalized health functional food pilot project provide professional and reliable services based on consumers' presentation of their health status, eating habits, DTC genetic test results, etc.	Herbalife Korea	Personal genetic information on 11 factors including body mass index, triglyceride concentration, cholesterol, blood sugar, blood pressure, caffeine metabolism, vitamin C concentration, skin aging, skin elasticity, pigmentation, and hair thickness
		Dongwon F&B	Genes related to basic nutritional status such as vitamins and selenium and genetic factors such as insomnia, obesity, and muscle were tested by targeting 50 genes
		Medigen Human Care	Genes are extracted through blood or saliva collection, and through the MELTHY system, a DTC genetic test service, health care areas such as exercise, skin care, and health management of the examiner

DTC, direct-to-consumer; DNA, deoxyribonucleic acid; BRCA1, breast cancer type 1; BRCA2, breast cancer type 2; UK, United Kingdom; EMQN, European Molecular Genetics Quality Network; BRAF, B type Raf kinase; EGFR, epidermal growth factor receptor.

problem was solved with a smartphone security app (30). The Pixacare software suite is designed to meet these needs in complete security. It is reported that this includes mobile applications, web applications, and Hydrometeorological Automated Data System (HADS) servers. Therefore, we suggest the necessity of developing a smartphone app for DTC genetic test security for skin health (30,31,40).

Discussion

Main findings of this study

This review found that the world has quickly become personalized after COVID-19 social distancing. According to the nano society, attention has been paid to individual skin health (4,22,25,29). This situation has led to increasing

Table 4 Pivotal items allowed for DTC genetic testing in Korea (source: Ministry of Health and Welfare)

Division	Allowed DTC genetic testing
Nutrient	Vitamin C concentration, vitamin D concentration, coenzyme Q10 concentration, magnesium concentration, zinc concentration, iron storage and concentration, potassium concentration, calcium concentration, arginine concentration, fatty acid concentration, vitamin A, vitamin B6, vitamin B12, vitamin E, vitamin K, tyrosine, betaine, selenium, lutein & zeaxanthin
Work out	Strength exercise, aerobic exercise fitness, endurance exercise fitness, muscle development ability, sprinting ability, ankle injury risk, grip strength, recovery ability after exercise
Skin/hair	Melasma/freckle, pigmentation, acne, skin aging, skin inflammation, tanning reaction after sun exposure, stretch mark/keratin, male pattern baldness, hair thickness, gray hair, circular hair loss
Eating habits	Appetite, satiety, sweet sensitivity, bitter taste sensitivity, salt taste sensitivity
Personal characteristics	Alcohol metabolism, alcohol dependence, alcohol flush, wine preference, nicotine metabolism, nicotine dependence, caffeine metabolism, caffeine dependence, insomnia, sleep habits/hours, morning/evening type, pain sensitivity
Healthcare	Degenerative arthritis susceptibility, motion sickness, obesity, uric acid level, triglyceride concentration, body fat percentage, body mass index, cholesterol, blood sugar, blood pressure, bone mass, abdominal obesity (waist-hip ratio), weight loss effect by exercise, weight recovery possibility after weight loss (yo-yo possibility)
Lineage	Find ancestors

DTC, direct-to-consumer.

Table 5 Problems with leakage of personal information from DTC genetic testing (n=48)

Detail	Quantity	Percentage (%)
An institution that has a website among non-medical genetic testing institutions	38	79.2
Institutions with posted privacy policies	18	37.5
Organizations that have posted that they are processing uniquely identifiable information	7	14.5
Institutions that do not publish safety measures	2	4.16
Institutions that can view genetic test results through their website	6	12.5

DTC, direct-to-consumer.

interest in the genetic potential of diseases across the entire genome (42). Accordingly, after wearing a mask since COVID-19, various methods for strengthening skin immunity and for maintaining and improving skin health and customized beauty products using DTC genetic testing have been proposed, however, continuous concerns about personal information protection remain unresolved. Ethical issues related to DTC genetic testing are also a major issue that needs to be identified (43).

Why are consumers focusing on skin healthcare after COVID-19?

Since the COVID-19 pandemic (6,36,44), consumer interest in skin healthcare increases even more (36,44,45). This is due to continued skin problems such as flushing of the skin (41), moisture, transepidermal water loss (TEWL) (46), skin secretion, and skin temperature as a result of the continued wearing of masks (46,47). After the end of the COVID-19 pandemic and the removal of the mask-wearing policy (48,49), consumers regain and increase their interest in skin healthcare (49-51). This can be seen from the increase in interest in immunity against continuous infectious diseases and the desire for healthy beauty (37,38,51-53).

Why does individual prefer non-contact DTC genetic testing after COVID-19?

In recent years, non-face-to-face treatment has been implemented in the medical field. The adoption of

telemedicine is bringing many advantages. Many patients are changing their lives in various ways due to the COVID-19 pandemic. The US Department of Health and Human Services has also declared a public health emergency and has consciously adopted telemedicine. This is essential and is bringing great help in situations where social distancing is required. Cognitive therapy is also being offered and practiced using existing communication technologies (54). Research on telemedicine use during COVID-19 may support this. It has had a profound impact on providing face to face clinical care and clinical research. During the COVID-19 pandemic, various non-face-to-face methods have been adopted and progressed in clinical practice and research of Parkinson's disease (PD) (40). Accordingly, the development of "non-contact" medical smartphone applications has been progressed at a rapid pace. A wireless and battery free sensor has been developed. A custom smartphone application can also be used to monitor heart rate and body temperature. Such an inexpensive and convenient healthcare system will continue to be developed further in the future. In addition, customized medical devices based on the Near Field Communication (NFC) system are being designed. A study on custom manufacturing developed a smartphone application for real time data collection and processing. Popularization of a wireless wearable medical system has been proposed to provide an inexpensive and practical route. In addition, the proposed platform does not directly go to experts for measured health information. It can easily be delivered to patients for non-contact, personal health consultation (55). Accordingly, the demand for DTC genetic testing, which allows consumers to manage their health through direct testing without visiting a hospital, is expected to increase further (40).

What are the benefits of DTC genetic testing for skin healthcare?

DTC genetic testing has the convenience of allowing consumers to undergo genetic testing directly through a specialized institution without having to visit a medical institution (4,11,12). Recently, as consumers' interest in health and desire to be beautiful increase, their interest in pursuing healthy beauty is increasing. In addition, recently, interest in individuals has become so focused that it can be called a nano society, and consumers are focusing on "personalization" (4,8,11,12,40). Accordingly, genetic testing DTC genetic testing is attracting attention along with increasing interest in customized health care and will continue to provide such healthcare in the future. The customized beauty market will continue to grow (25,27-40).

What is already known about this topic, and what does this study add?

In previous studies, several studies have been conducted on skin health with customized cosmetics and customized inner beauty by applying DTC genetic testing (16,17,22,25,35). However, there has been no precedent study that suggests improvement measures on concerns about the leakage of personal information about DTC genetic testing. Sharing genetic test results is a key clinical health behavior in genomic medicine (56). There is development potential of DTC genetic testing for sustainable skin health. In addition, it is necessary to secure additional safety by developing a mobile app for the sharing of personal information of DTC genetic test information. Online testing formats, which benefit from their accessibility and affordability, are becoming increasingly popular. However, it raises concerns from consumers and regulators about the accuracy and reliability of the results, data security, and consumers' privacy protection (55,57). This opens new possibilities. Based on the research results, it is expected that it will be used as an important marketing material to respond to new changes in the customized dermatological cosmetics market at the time of hyper personalization.

Research limitations

Although this study was carried out by systematically increasing the relevance of the study, there are some limitations. This study is consistent and credible with key findings from systematic reviews. In addition, two researchers conducted individual tests several times to secure relevant scientific articles. It is also based on a new recalibrated algorithm. However, despite this standardized analysis, it is recognized that there are two limitations. First, the small number of articles is a limitation due to the lack of prior studies. This is confirmed by the fact that research on the information security of DTC genetic testing is still lacking. Second, there is a lack of additional studies on the ex-tension of the applicability and side effects of DTC genetic testing. For example, some factors could not be clarified in the review because the data were not be able to

be collected in the review. Therefore, additional research on the information security of DTC genetic testing should be continuously conducted.

Future research

The limitation of this study is that additional research is needed on the safety and sustainability of DTC genetic testing, which is still emerging. Therefore, for the expansion of this study, research on customized dermatological cosmetic formulas and development of various security applications for the Web 3.0 era will need to be continuously conducted (30,31,40). For DTC genetic testing to remain sustainable to consumers, as a follow-up study, we plan to conduct research of a quantitative study to secure the possibility of the development and to gain information on the specific awareness on the development of an app for information security of DTC genetic testing in the Republic of Korea (58,59).

Conclusions

This study suggests the potential development of DTC genetic testing for sustainable skin healthcare. Research has been conducted on customized cosmetics and inner beauty with DTC genetic testing, but there has been no research suggesting improvement measures to address concerns about personal information leakage regarding DTC genetic testing. It also opens new rooms for discussions on the accuracy and reliability of results for privacy, data security, and ways to protect the privacy of consumers and regulators. However, a limitation of this study is that there is still a lack of research on the information security of DTC genetic testing. Additionally, there is a lack of additional research on the applicability together with the side effects of DTC genetic testing. Accordingly, we will conduct additional quantitative research to investigate specific perceptions of information app development and secure development possibilities. For the development of safe beauty services for sustainable skin healthcare, it is necessary to secure the safety of the processing and sharing of DTC genetic testing information. Therefore, we proposed a method of using mobile security applications to ensure sustainable safety. It is expected to be used as an important marketing material in response to new changes in the customized inner beauty mobile app and dermatological cosmetics market.

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Footnote

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