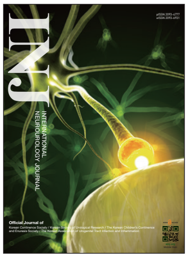

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New Trends in Innovative Technologies Applying Artificial Intelligence to Urinary Diseases

Jin Kyu Oh[1], Jun Young Lee[2], Sung-Jong Eun[3], Jong Mok Park[4]

[1]Department of Urology, College of Medicine, Gachon University, Incheon, Korea
[2]Department of Medical Device Engineering and Management, Yonsei University, Seoul, Korea
[3]Digital Health Industry Team, National IT Industry Promotion Agency, Jincheon, Korea
[4]Department of Urology, Chungnam National University Sejong Hospital, Chungnam National University College of Medicine, Sejong, Korea

Artificial intelligence (AI) is used in various fields of medicine, with applications encompassing all areas of medical services, such as the development of medical robots, the diagnosis and personalized treatment of diseases, and personalized healthcare. Medical AI research and development have been largely focused on diagnosis, prediction, treatment, and management as an auxiliary means of patient care. AI is mainly used in the fields of personal healthcare and diagnostic imaging. In urology, substantial investments are being made in the development of urination monitoring systems in the personal healthcare field and diagnostic solutions for ureteral stricture and urolithiasis in the diagnostic imaging field. This paper describes AI applications for urinary diseases and discusses current trends and future perspectives in AI research.

Keywords: Artificial intelligence; Smart toilet; Uroflowmetry; Mobile urination log; Urinary system disease

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INTRODUCTION

In the era of the Fourth Industrial Revolution, the utilization of exponentially increasing data has been recognized as a matter directly related to industrial competitiveness. Most industrial fields are struggling to handle overflowing information and data more efficiently and productively, and successfully coping with this challenge is considered to be directly related to companies' survival in business. As such, the importance of artificial intelligence (AI) is increasing as a way to facilitate the analysis of huge amounts of information [1]. With the shift in the focus of AI from creating new information and knowledge by simply using data to developing and evaluating services, the applications of AI in the medical industry have also expanded. The introduction of AI technology to the medical field is also likely to have extensive ripple effects on society; therefore, many compa-

Corresponding author: Sung-Jong Eun https://orcid.org/0000-0003-3063-0452
Digital Health Industry Team, National IT Industry Promotion Agency, 10 Jeongtong-ro, Deoksan-eup, Jincheon 27872, Korea
Email: sjeun@nipa.kr
Co-corresponding author: Jong Mok Park https://orcid.org/0000-0002-4430-7851
Department of Urology, Chungnam National University Sejong Hospital, Chungnam National University College of Medicine, 20 Bodeum 7-ro, Sejong 30099, Korea
Email: jm0113@hanmail.net
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nies and countries have made substantial investments in medical AI.

AI is used throughout the medical system, encompassing all areas of medical services, such as the development of medical robots and the diagnosis and treatment of diseases. The rapid introduction of medical AI is expected to enhance the quality of medical facilities and services in the near future, thereby extending patients' lives and improving their quality of life. The advent of AI was one of the largest advances in technology in history; from smartphones to surgical robotics, AI has changed society in monumental ways. As AI technology continues to develop, its applications in medicine will expand even further. In medicine, AI can be divided into 2 types: virtual and physical. Virtual AI includes information science and system-based learning, such as the deep learning-based management of symptoms that guides treatment decisions. Physical AI includes robots and nanotechnology to improve drug delivery. Both sectors of AI can contribute to remarkable improvements in patient care. These new tools and functions will have much-needed impacts, especially in urology.

The application of AI will be beneficial in several fields of urology, including both benign urological conditions and cancer. The use of AI to analyze vast amounts of data for diagnosis and prognosis is expected to be particularly beneficial. Machine learning (ML) is an AI field that integrates statistics and algorithms to find relationships in data. These tools can be applied to clinical data to generate robust risk models and redefine the classification of diseases. As medicine advances into the era of "big data" with an increasing amount of complex medical data, ML can be a powerful resource for exploring, explaining, and applying information. This review paper discusses trends in AI applications in urology, focusing on self-management and diagnostic support systems, and presents an overview of future prospects and limitations.

TRENDS IN THE USE OF AI FOR URINARY DISEASES

Medical AI research and development have been largely focused on diagnosis, prediction, treatment, and management as an auxiliary means of patient care. AI is mainly used for personal health management and diagnostic imaging assistance. In urology, substantial investments are being made in the development of urination monitoring systems in the personal healthcare field and diagnostic solutions for ureteral stricture and urolithiasis in the diagnostic imaging field. This paper aims to describe AI applications in the field of personal health management and diagnostic imaging and to discuss future perspectives in AI research.

AI Applications in the Field of Urinary Health Management

In the domestic mobile medical device industry, Samsung and LG are leading the development of portable products and launching them in the market, and the market for portable healthcare-related devices and services such as wearable devices is steadily expanding. These devices can be broadly classified as smart healthcare products. Below, we introduce examples of these products specializing in urinary healthcare.

Yodoc-m (Korea) is a South Korean ubiquitous-based product that enables self-diagnosis by uploading the results of urinalysis onto a web-based server and allows the user to monitor his or her urinalysis results in real time. It claims to be the most fundamental system for monitoring users' urination, as most domestic urination monitoring products are based on its framework. Fig. 1 shows the user interface screen of Yodoc-m.

Diverse products have also been developed internationally. For example, Toilet Tracker (Toronto, Canada) allows users to directly input their number of defecations/urinations during a day on a smartphone and displays the time of the last urination/defecation. The app presents statistical data visualizations based on the entered data on urination/defecation.

Biosense Technologies Private Limited (Maharashtra, India) provides an image-based urinalysis function using a mobile terminal by smearing urine on a test strip. It can detect 25 diseases, including diabetes, urinary tract infection, and preeclampsia and measure levels of glucose, protein, and ketone. SYMAX (Tokyo, Japan) provides a healthcare check service that detects 17 diseases based on urination into the toilet bowl. A sensor pre-installed in the toilet measures urine components,

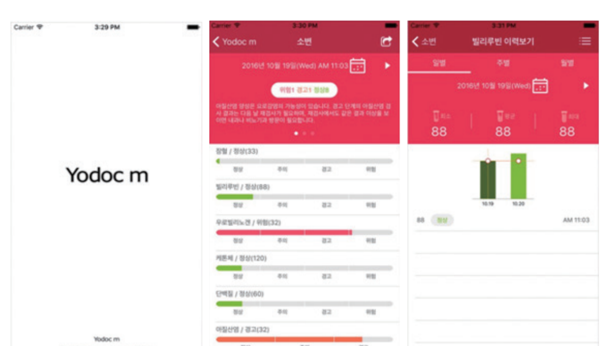

Fig. 1. Functions and user interface of the Yodoc-m product.

transmits the data to a cloud server, and presents the analysis results on the terminal. These systems provide a core service in routine health check-ups. Fig. 2 shows information on these international products.

Smart toilet services have been developed through the integrated construction of systems and devices. These services support precise healthcare by collecting and analyzing data on urination and defecation. Domestic and international institutions are promoting smart toilet services with the aim of realizing digital healthcare based on AI and Internet of Things (IoT) technology. First, Japan's TOTO Ltd (Kitakyushu, Japan) is producing the Wellness Toilet concept product, which includes odor sensors to detect health conditions and problems such as stress, and also suggests a desirable lifestyle based on the provided information. Panasonic also launched a smart toilet in China that collects urine and tracks body fat. In addition, a smart toilet launched by Toi Labs, an American startup established in 2015, is being provided for elderly individuals with genitourinary and gastrointestinal problems; the product measures the size, color, and consistency of excretions to detect health problems in the early stage.

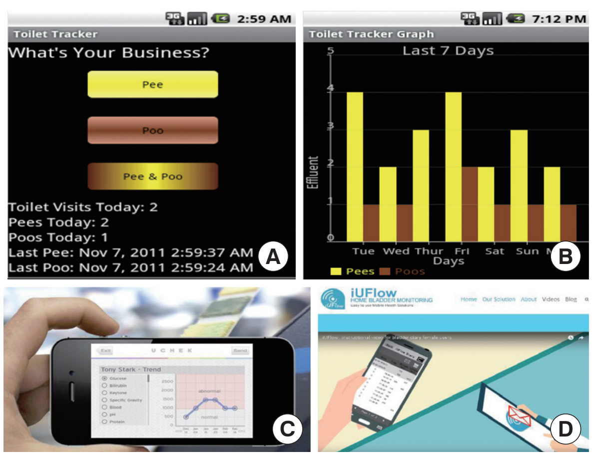

Fig. 2. Major international products related to urinary healthcare. (A, B) Toilet Tracker product (BeakSoft, Toronto, Canada). Biosense product (Biosense Technologies Private Ltd., Maharashtra, India) (C), SYMAX product (SYMAX, Tokyo, Japan) (D).

China is also investing heavily in the development of health management systems using big data, and Geometry Healthcare, a Chinese startup, released in August 2020 a smart toilet seat that allows users to check their health. It provides healthcare advice using a biochip and special algorithm that continuously monitors approximately 30 biomarkers or measurable body characteristics.

Research institutes both n South Korea and abroad are also actively engaging in research on smart toilet systems. A team led by Professor Joshua Coon at the University of Wisconsin-Madison is conducting research on technology that diagnoses the health of toilet users through urine, which is relatively easy to collect and analyze. As there are thousands of small molecules in urine, properly analyzing the data could make it possible to determine which diseases are likely to occur in the future. Joshua Coon's research team explained that urine samples can be used to identify molecules that correlate with the way ingested drugs are absorbed or excreted, dietary fat content, and consumed calories. Researchers at the Stanford School of Medicine are also working on a technology that could track and test the speed and color of urine. The Stanford researchers partnered with Izen, a South Korean toilet manufacturer, to build a prototype. Seoul Songdo Hospital in South Korea also participated in this research. Fig. 3 shows the concepts of these smart toilet products.

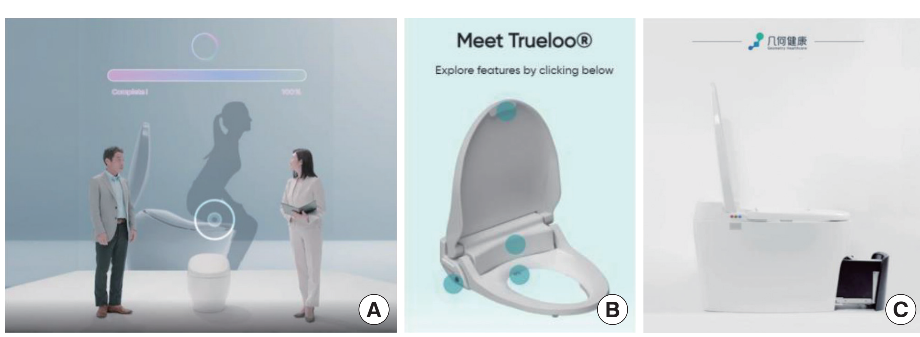

Fig. 3. Major international smart toilet service products. (A) Wellness Toilet explanation image from Toto homepage (https://www.toto.com/). (B) The image from the Toi Labs homepage (https://www.toilabs.com/). (C) Geometry Healthcare smart toilet from the Geometry Healthcare homepage (https://www.compasslist.com/startups/geometry-healthcare).

AI Applications in the Field of Urinary Disease Diagnosis

AI research has been conducted for various urinary diseases—namely prostatic hyperplasia, ureteral stricture, urolithiasis [2-9], and urinary tract infections. AI is mostly used as an auxiliary means of disease diagnosis by clinicians, and it is essential to verify the application effectiveness of AI technology through many clinical trials. As a result, it was possible to identify fields and technologies with high potential for application in the medical field, and the current paper introduced some of the major cases by technology field (sound signal and image data).

First, researchers at Seoul National University Bundang Hospital developed mobile uroflowmetry technology through acoustic signal analysis. As early as 2017 and 2018, they conducted an internal performance evaluation of the uroflowmetry technology through clinical trials to confirm its effectiveness. The software equipped with this technology is a medical device with acoustic analysis-based uroflowmetry software and was registered as a Class 2 medical device with the U.S. Food and Drug Administration (FDA) in 2020. The technology measures the pattern of urination based on acoustic analysis and AI and enables a noninvasive examination using a smartphone. It automatically records and displays data graphs of voided volume, maximum flow rate, and voiding time based on the sound produced when urine touches water and stores measurement data on the dashboard. The applied AI technology involved linear/nonlinear regression analysis, classification analysis, and deep learning. Fig. 4 shows the workflow of this device.

In addition, researchers at Gachon University Gil Hospital developed an assistive technology [10] that can help diagnose urinary diseases by analyzing the urination posture (i.e., movement signals collected through the gyro and acceleration center). First, the research team developed a urination log app that supports the automatic creation of a urination log for patients with urinary diseases. Among male users, urination is classified into 3 categories—preurination, during urination, and posturination—to facilitate an automatic analysis of the user's urination frequency, duration, and volume through learning and recognition. The technological underpinnings of the app are AI learning and the recognition of urination motions, for which various ML and deep learning techniques were used. Figs. 5 and 6 show the process and concept of the research [11].

Researchers at Sejong Chungnam National University Hospital are exploring techniques [12] to use imaging data, such as microendoscopy and computed tomography (CT), to assist in the diagnosis of diseases such as ureteral stricture and urolithiasis. The importance of assistive diagnosis research on ureteral stricture lies in the fact that it is often difficult to determine the stricture site during surgery, which makes stricture site removal challenging. For decision support, AI technology is used to automatically recognize the stricture site from the ureteral imaging obtained through microendoscopy, thereby supporting the clinician as he or she performs surgery. The AI technology used provides recognition information in real time by utilizing deep learning technology, such as ResNet-50 [13-17]. Fig. 7 shows a concept map of this research [18].

In addition, research is actively being conducted to support

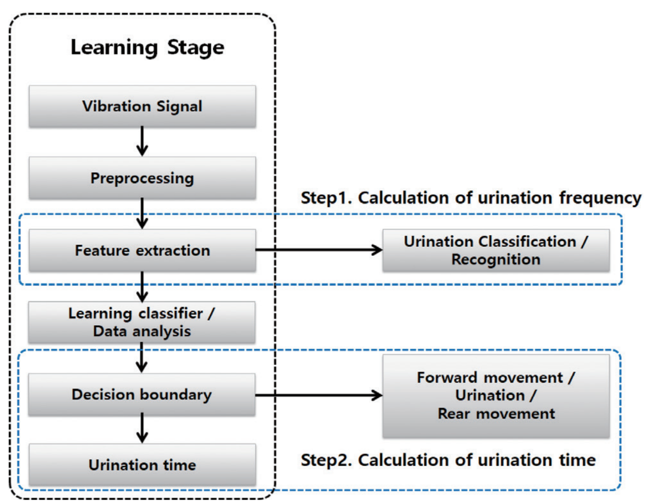

Fig. 5. Algorithm process for the recognition of urination.

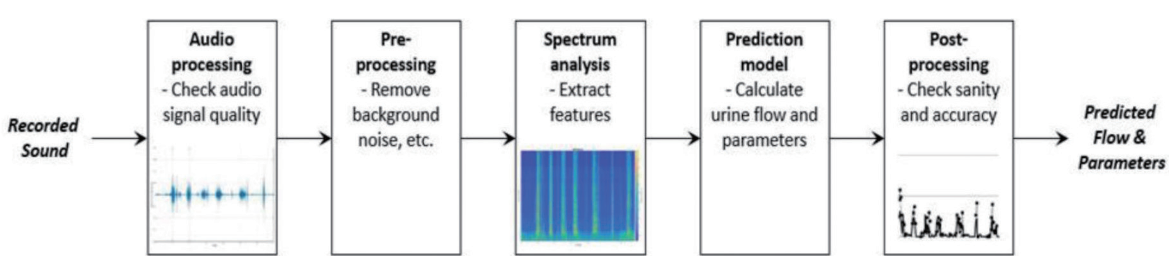

Fig. 4. Flowchart of the algorithm used in mobile uroflowmetry technology.

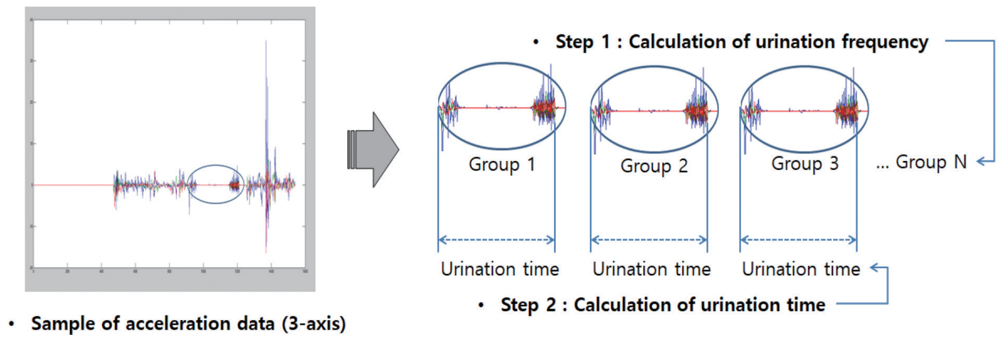

Fig. 6. Concept map for recognition of urination [11].

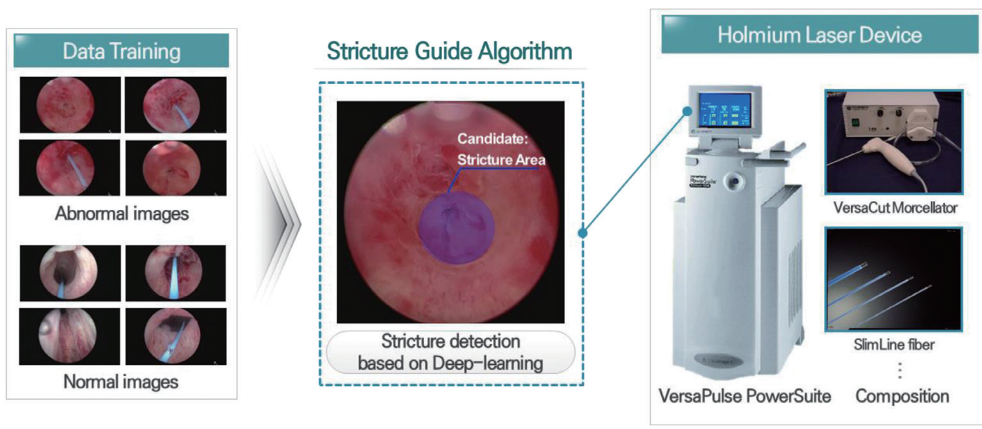

Fig. 7. Concept map of a surgical assistance system for ureteral stricture [18].

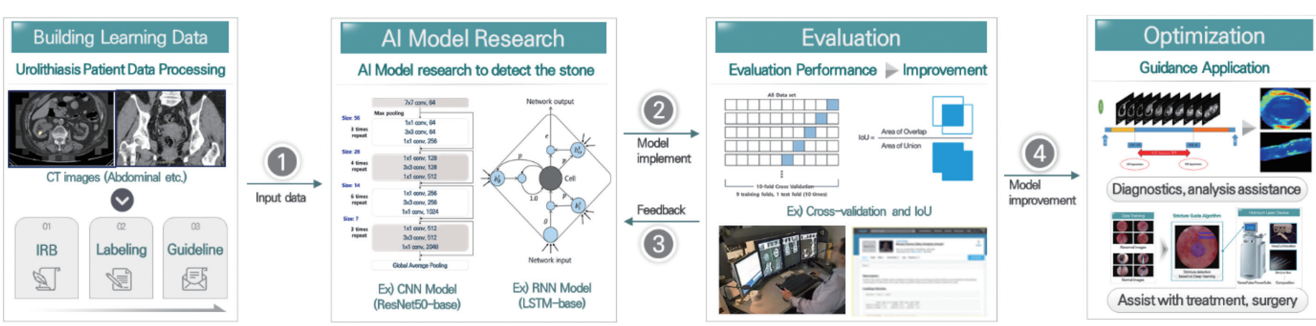

Fig. 8. Concept map of research on an algorithm for urolithiasis recognition [21].

the diagnosis of urolithiasis by utilizing abdominal CT and C-arm imaging data, since a correct diagnosis is of the utmost importance for the surgery and treatment of urolithiasis. To support the diagnosis of urolithiasis, research on technology [19] that automatically diagnoses urolithiasis and evaluates its status based on imaging data is underway. To this end, research has explored the optimal technological methods in terms of image processing (Watershed), ML, and deep learning (ResNet-50, Fast-RCNN [20]). Fig. 8 shows a concept map of this research [21]. In this section, we examined some examples of research on sound and image signal analysis as examples of AI in urinary disorders.

CONCLUSIONS

In this paper, we presented applications of AI technology in urinary system diseases and discussed the current trends and future directions. To this end, some domestic and international cases and research on personal healthcare services and disease diagnosis assistance were reviewed. For personal healthcare services, many monitoring app services have been developed for the prevention and management of urinary system diseases, most of which involve automatically recording and analyzing the user's urination information based on the input text and signal data collected by IoT devices to determine and predict the user's health condition. These advances underscore the importance of pre- and post-management of urinary system diseases and the gradually increasing demand for solutions in this field. However, rather than the professional diagnosis of urinary system disease, health management or disease management was the focus of these services, which were developed in the context of existing digital healthcare. In contrast, research focusing on supporting the diagnosis and analysis of diseases has mainly dealt with the recognition of specific diseases, such as ureteral stricture and urolithiasis. This research aims to help with clinicians' final diagnosis and support surgery by identifying the presence of a disease and conducting morphological analyses, such as assessing the location of problematic areas based on image analysis of strictures and stones.

These examples of AI applications were largely focused on signal analysis and image analysis for various purposes, such as disease prediction, management, diagnosis, and analysis. The level of AI technology used was high in most cases. A variety of advanced AI technologies have been studied based on representative analysis technologies, such as recurrent neural networks for signal analysis and convolutional neural networks for image analysis.

Furthermore, gradual preparations for application are made in the medical field. For these services to be properly applied at home or in medical contexts, many issues should be resolved, such as verification of their effectiveness and medical device certification. There are procedural requirements that go beyond the R&D level, such as commercialization through institutional investment, validation of effectiveness through clinical verification, and medical device certification by the U.S. FDA and the Korean Ministry of Food and Drug Safety. In other words, for successful commercialization and real-world utilization, it is necessary to take costs other than those associated with R&D into consideration. It seems that we have already passed the stage of verifying the possibility of AI applications for urinary diseases in the field. In the future, in order for AI technology to be properly applied at home and in medical settings, more R&D support from diverse institutions is needed.

AUTHOR CONTRIBUTION STATEMENT

· Conceptualization: *SJE*
· Data curation: *JYL*
· Formal analysis: *JKO*
· Funding acquisition: *JMP*
· Methodology: *JKO*
· Project administration: *JYL*
· Visualization: *SJE*
· Writing - original draft: *JKO*
· Writing - review & editing: *JMP*

ORCID

Jin Kyu Oh 0000-0002-5043-411X
Jun Young Lee 0000-0003-0698-2036
Sung-Jong Eun 0000-0003-3063-0452
Jong Mok Park 0000-0002-4430-7851

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