



From digits towards digitization: the past, present, and future of traditional Chinese medicine

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ARTICLE INFO	ABSTRACT
<p>Article history Received 09 February 2025 Accepted 12 February 2025 Available online 25 March 2025</p> <p>Keywords Traditional Chinese medicine (TCM) digitization Modernization of TCM Interdisciplinary integration</p>	<p>Digitization is the inevitable path for the natural development of traditional Chinese medicine (TCM) in the context of the Fourth Industrial Revolution. The goal of TCM digitization is to generate intelligence from numbers. Originating from the reasoning paradigm of Xiangshu (象数, image-number) or phenotype-numerology thinking, TCM came with a deep correlation of clinical observations with digits and laid a strong theoretical basis for digitization. The digitization of TCM should start from the clinical aspect, solve the problem of electronic medical records, achieve standardization and informatization, and on this basis, form a TCM knowledge base through knowledge-building. This process depends on the combined efforts of multiple disciplines such as medicine, mathematics, and engineering to achieve the digitization and intelligent transformation of TCM. This era calls for TCM to break down barriers, embrace opportunities, and move towards digitization. However, during the transformation, it should maintain its essence, avoid simplistic conversions, be guided by scientific value, leverage cutting-edge technologies, and enhance the depth and breadth of the interpretation of TCM connotations. The digitization of TCM will also improve its service capabilities, create an innovative digitally-intelligent TCM service platform, and contribute to the development of “Healthy China” initiatives with wisdom and solutions.</p>

1 Introduction

On October 18, 2021, President Jinping XI emphasized during the 34th Group Study Session of the Political Bureau of the 19th CPC Central Committee: “In today’s era, digital technologies and the digital economy represent the forefront of global scientific revolutions and industrial transformations. They are pivotal in the new round of international competition. We must seize this opportunity and take over the commanding heights to secure strategic advantages for future development” [1]. Historically, the First Industrial Revolution transitioned humanity from an agricultural civilization to an industrial one,

the Second Industrial Revolution ushered the “Electrical Age”, and the Third Industrial Revolution was marked by the emergence of information technology. Each industrial revolution has had a profound and far-reaching impact on human production and lifestyles [2]. Human society has entered an era characterized by the in-depth integration of information and digital technologies. A new round of scientific and technological revolution and industrial transformation, with the gradual coverage of urban and rural areas by artificial intelligence (AI), big data, cloud computing, and fifth-generation (5G) networks, has changed our lifestyle, economic structure, and social pattern, and has propelled the process of social and historical

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development [3]. Currently, the Fourth Industrial Revolution is bringing about another leap in productivity. Digital technology is driving the world's scientific and technological revolution and industrial transformation, endowing them with new connotations. Digitization has permeated all sectors of society, accelerating the advancement of medicine and the sophistication of the medical technology structure [4]. PEREZ et al. [5] have noted that every change in technological paradigm will be accompanied by both barriers and windows of opportunity. TCM, with its thousands-year-old original thinking based on the "phenotype-numerology thinking model", that reveals the essential laws for understanding the world through analogy and symbolization such as images, symbols, and numbers, needs to break down barriers and seize opportunities in this era, and should achieve digital transformation in the new round of scientific and technological revolution. The realization of TCM digitization landed in the following key aspects: (i) tracing back the origins to clarify the digital foundations of TCM; (ii) seeking truth through practice to explore the digital path of TCM; and (iii) employing interdisciplinary integration to envision the prospects of TCM digitization. That is the past, present, and future of TCM digitization.

2 TCM originated from digits: the theoretical origin of TCM digitization under Xiangshu (象数, phenotype-numerology) thinking

2.1 The relationship between the original Xiangshu thinking in TCM and the books of *Hetu Luoshu* (《河图洛书》) with *Yijing* (《易经》)

Based on the "Research on TCM Original Thinking and Health State Identification Method System", a project supported by the National 973 Program, the authors

proposed that the original thinking of TCM manifests as a holistic paradigm with an integrated thinking mode of Xiangshu thinking, unity of form and spirit, and Qi (气) as the primordial essence (Figure 1) [6]. The concept of phenotype-numerology in Xiangshu thinking is one of the elements of TCM's original thinking mode, characterized by the integration of Xiang (象, phenotypes based on phenomenological observation) with Shu (数, digits in the numerological modeling), prioritizing Xiang as the foundation of main focus and Shu as the means of operational tool, involving inductive and deductive methodologies [6]. Xiangshu thinking encompasses two dimensions: Quxiang (取象, phenotypical reasoning or phenotype-based thinking), and Yunshu (运数, numerological reasoning, or numerology-based thinking). As Bing WANG annotated in the book of *Suwen* (《素问》, *Plain Questions*): "Xiang refers to externally observable and interpretable manifestations" [7]. The methodology of Quxiang originates from the *Yijing*, where Xiang serves as a cognitive tool to observe, interpret, and analogize natural and human phenotypes [8]. Therefore, Xiang includes the objective physical phenotypes of externally observed and examined and the subjective phenotypes of mental images, perception and understanding. Shu refers to the deductive process of classification and symbolization using calculation methods and involves the application of mathematical methods for analogy, symbolic deduction, and predictive modeling. The book of *Yizhuan* (《易传》, *Ten Wings*) proposes the tripartite thinking process, namely (i) Yishu (倚数, relying on numbers), quantifying phenotypes through mathematical metrics; (ii) Jishu (极数, exhausting numbers), exploring the changing laws of numbers and numerical patterns to their limits; (iii) Nishu (逆数, inverse numerology), inferring the future by reversing numbers and retrospective analysis for

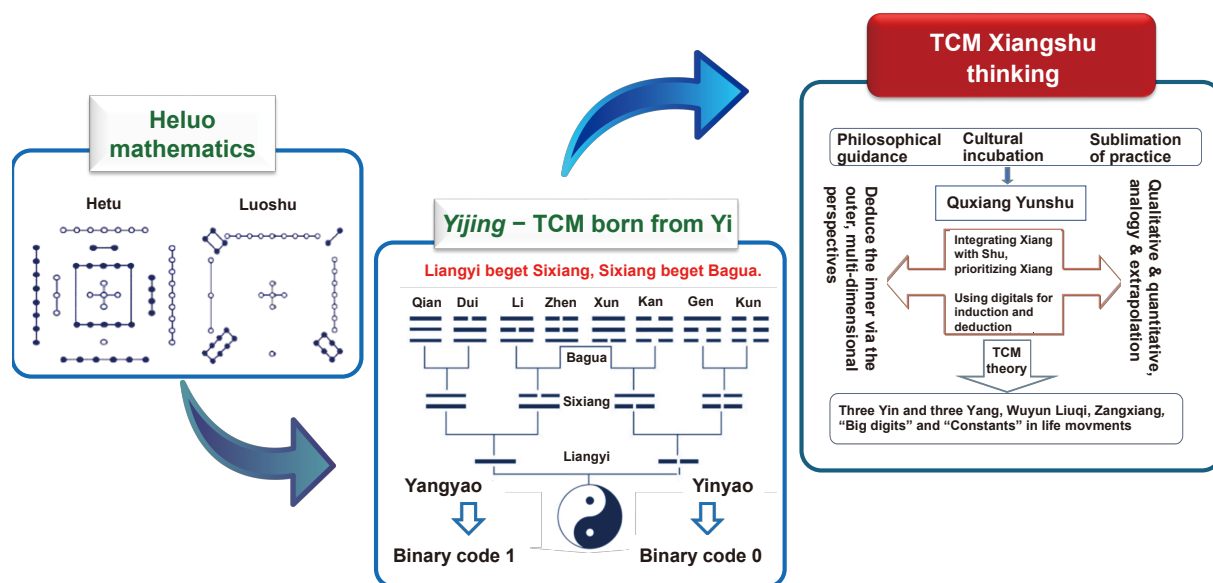


Figure 1 The theoretical origin of TCM Xiangshu thinking

future prediction. This framework of “relying on numbers-exhausting numbers-reversing numbers” reflects the dialectical unity of “Shu as the manifestation of Xiang, and Xiang as the determinant of Shu”—a proto-mathematical modeling process foundational to TCM^[9], which exactly reflects the process of establishing a mathematical model with numbers indicating phenotypes and phenotypes determining numbers.

Jiebin ZHANG, a physician in the Ming Dynasty, comprehensively expounded on the principle of “the interconnection between medicine and Yi (易, changes) sharing common origins” in Attached Supplement of his book of *Leijing Fuyi · Yiyi* (《类经附翼·医易》), the *Categorized Classic-Medicine and Yijing*). He pointed out that “The unity of heaven and man lies in the unity of Yin and Yang (阴阳); the common origin of medicine and the Yi laid in their mutual embodiment of transformative principles of changes”^[10]. Both TCM and the *Yijing* derived theoretical foundations from the book of *Hetu Luoshu* (Figure 1). As stated in the *Yijing · Xici* (《易经·系辞》): “The River brought forth the Chart, the Luo brought forth the Writings—the sages modeled after them”^[11]. Originally constructed by ancient Chinese sages to map celestial patterns (star arrangements), temporal cycles (seasons), and spatial orientations as astronomical-calendrical diagrams, the *Hetu Luoshu* employed black/white dots to encode spatiotemporal concepts through digital symbols and temporal sequences. These were served as the genesis of the principles of Yin-Yang theory, Liangyi (两仪, two forms), Sixiang (四象, four images), Wuxing (五行, five elements), Bagua (八卦, eight trigrams), Shitiangan (十天干, ten celestial stems), and Shierdizhi (十二地支, twelve earthly branches), thus regarded as the “Cosmic Rubik’s Cube” and evolved into universal models with the unified law^[12]. Notably, the famous mathematician Luogeng HUA (华罗庚) once speculated that “The *Hetu Luoshu* may very likely be the medium of communication between our earth civilization and another planet”^[13].

The Xiangshu principles embedded in the *Hetu Luoshu* were further expounded in the book of *Yijing* (Figure 1). Xi ZHU (朱熹), the eminent neo-Confucian scholar in the Southern Song Dynasty, positioned these diagrams at the forefront of *Zhouyi Zhengyi* (《周易正义》, *The Correct Meaning of Yijing*), affirming their status as the dual cornerstones of *Yijing* philosophy. In *Yijing*, the Yang and Yin lines on a trigram represent the binary mathematical structures. Later, from Taiji (太极, Tai Chi), Liangyi were generated. From Liangyi, the Sixiang were born. From Sixiang, Bagua were derived. Legend attributed Fuxi’s creation of Bagua to his synthesis of the *Hetu Luoshu* with Suireshi’s star-chart calendar systems, “capturing the affinities of all things” through trigrams. The 64 hexagrams evolved from Bagua form a symbolic system mapping universal interrelationships. The incorporation of Bianyao (变爻, changing lines on a

trigram) as dynamic parameters exemplifies *Yijing*’s core tenet: Xiang and Shu are inseparable—where numerological patterns encode phenomenological truths, and vice versa, reflecting the intrinsic laws governing cosmic and human phenomena. By further introducing the changing lines as variable parameters, numbers contain phenotypes and phenotypes contain numbers, reflecting the idea of “the unity of phenotype (Xiang) and numerology (Shu)” in the book of *Yijing*. Phenotype and numerology together constitute the internal connections and laws of all things in the universe.

2.2 Applications of Xiangshu (phenotype-numerology) thinking in TCM

The *Hetu Luoshu* numerological framework, a cornerstone of *Yijing* studies, has had a profound impact on the establishment of the TCM theory and Fangji (方剂) system, covering aspects such as the physiological functions of the human viscera, pathological changes, the relationship between climate and disease onset, and the dosage compatibility of clinical Fangji selection through its embedded Xiangshu principles^[14, 15]. The core of the TCM’s visceral manifestation theory is “Zangxiang (藏象) theory”, which is to observe the phenotypes of the living body, infer the internal organs from the phenotypes, and finally classify according to the phenotypes, to understand the physiological and pathological laws of the human body and its relationship with nature, forming the Zangxiang. At the core of TCM’s Zangxiang theory was Huoti Quxiang (活体取象, the living-body phenotypes define the visceral manifestation). Phenotypes are analyzed to deduce visceral functions, linking human physiology/pathology with cosmic-natural rhythms, ultimately forming Zangxiang. Hetu combines ten numbers with the phenotypes of the five directions, five phases, and Yin-Yang correspondences. For instance, 1 and 6 for Water-North; 2 and 7 for Fire-South; 3 and 8 for Wood-East; 4 and 9 for Metal-West; and 5 for Earth-Center, forming the numbers of the viscera, which are directly related to the positioning of the viscera, physiological and pathological conditions, and adaptability of seasonal changes in TCM Zangxiang theory. The correspondence between the five visceral organs and the four seasons-five directions in *Suwen · Jinkui Zhenyan Lun* (《素问·金匮真言论》) originated from the Hetu. *Lingshu · Jiugong Bafeng* (《灵枢·九宫八风》, *The Miraculous Pivot: Nine Palaces and Eight Winds*) exemplifies the Luoshu’s clinical application, mapping spatial orientations and seasonal winds to pathogenic patterns, thereby elucidating geographic-temporal influences on health^[16].

The *Suwen · Shanggu Tianzhen Lun* (《素问·上古天真论》) indicated that “Fa Yu Yinyang, He Yu Shushu” (“法于阴阳, 和于术数”, the adherence to the laws of Yin-Yang and harmony with the numerological techniques)^[17].

The Yin-Yang dialectic reflects the binary philosophy of looking at the world. Niels Bohr used the Taiji diagram element in designing his family crest, believing that it could perfectly explain his complementarity theory, and inscribed the motto “Contraria Sunt Complementa” (opposites are complementary) [18]. German scholar Schönberger’s *The I Ching & the Genetic Code: The Hidden Key to Life* [19] further revealed a striking alignment, which is the 64 hexagrams can correspond to the 64 genetic codons, with three stop codons matching the hexagrams Kui (睽, stagnation), Guimei (归妹, return), and Sun (损, loss), all of which imply the meaning of halting or termination. The balance and stability formed by the generation and restriction relationship of “Yin and Yang” is the generation and restriction of the Wuxing theory, which constituted the earliest known network model with synergistic (generative) and antagonistic (restrictive) protocols. Studies have demonstrated that the equilibrium in the five-phase network requires synergistic strength ($a + b$) to exceed antagonistic strength ($c + d$), with optimal balance achieved when $(a + b)/(c + d)$ increases to approximately 0.618 (an approximation of the square-root golden ratio 1.618), the five-phase network reaches the expected balance state [20].

The concept of Shushu (术数, numerological techniques) reflects the quantitative research on all things in the universe, implicitly containing the two-fold digital structure of Waisuan (外算, external arithmetic) and Neisuan (内算, internal arithmetic). Waisuan refers to the physical structure, such as the performance of various measurement and representation, as well as the manifestation of various modern engineering mathematics across multiple application fields. Neisuan refers to the numbers of life and other laws, which is the mathematical content related to the fundamental laws of the universe and the human body. In terms of Waisuan, the *Lingshu · Maidu* (《灵枢·脉度》) and *Lingshu · Changwei* (《灵枢·肠胃》) provided the numerical data of anatomy on visceral organs, meridians, and collaterals. In terms of Neisuan, the *Lingshu · Suilu* (《灵枢·岁露》) states, “Human beings are in harmony with heaven and earth and synchronize with the sun and moon” [21], reflecting the correspondence between the numerical rhythms of human life and natural cosmic cycles in TCM. For example, the 24 solar terms are a knowledge system formed by the ancients through observing the annual motion of the sun and understanding the changes in seasons, climate, and phenology. The onset, development, and progression of disease may correlate with these natural periodic rhythms [22, 23]. The theory of Ziwu Liuzhu (子午流注, midnight-midday ebb flow) is a circadian rhythm theory summarized by the ancients based on the law of the circulation of Qi and blood in the human body, which links time factors with biological rhythms. Since the 1980s, the discovery of rhythm-related genes, particularly

the molecular mechanisms of circadian clocks, has provided evidence that empirically validated the objectivity of TCM’s temporal medicine [24]. Modern studies have confirmed the significant correlations between the incidence and mortality of coronary heart disease and both the 24 solar terms and the 12 two-hour periods of the day [25, 26]. The *Huangdi Neijing* (《黄帝内经》, *Inner Canon of Huangdi*) further integrated the numerology of life-cycles into its Neisuan framework. For example, the *Lingshu · Tiannian* (《灵枢·天年》, *Miraculous Pivot: Natural Lifespan*) outlined the life-aging law with a “ten-year” cycle, i.e., the decadal aging cycles, while the *Suwen · Shanggu Tianzhen Lun* (《素问·上古天真论》) revealed the sexual-aging law of “women in sevens and men in eights” as gender-specific sexual maturation rhythms [27]. From the perspective of numerology, according to the Luo-shu’s nine-palace and eight-trigrams, a young girl corresponds to the Dui (兑), the 7th Palace, and a young boy corresponds to the Gen (艮), the 8th Palace. TCM physician Rongchuan TANG in the Qing Dynasty stated in his *Yiyi Tongshuo* (《医易通说》, the generalized interconnection between medicine and *Yijing*), “Before the arrival of Tiangui (天癸, heavenly tenth, menstruation), both young boys and girls correspond to the Gen and Dui hexagrams” [28]. From the astronomical perspective, the gravitational fluctuations of Jupiter and Venus may exert periodic influences on human physiology, and the combined action cycle is approximately 7.297 years. Due to the differences in Yin-Yang and anatomy, women and men are more closely related to Venus (7-year cycles) and Jupiter (8-year cycles) respectively [29]. From the perspective of neuro-endocrine-immune (NEI) network, there are significant differences in the changes of sex hormones and growth hormones in men and women across different age groups [30].

In TCM clinical practice of diagnosis and treatment, both phenotypic patterns (Xiang) and numerological principles (Shu) are taken into account and integrated with a balance of fixed norms with contextual variables. Therefore, one should know both the constant numbers and the variable numbers. For instance, while the onset of diseases follows predictable constant changes of rhythms governed by Wuyun Liuqi (五运六气, five circuits and six Qi), diagnosis and treatment must adapt to the variable numbers that need to be measured according to time, place, and individual conditions. *Shanghan Lun* (《伤寒论》, *Treatise on Cold Pathogenic Diseases*) has the phenotypes of “three Yin and three Yang (三阴三阳)” and the exterior-interior relationship, employed the phenotypical framework for Zhenghou (证候) differentiation. The design of formula, usually a composition of several herbs called Fufang (复方), for the treatment of the corresponding Zhenghou should adhere to hierarchical ratios of herb numbers such as “one Jun (君) and two Chen (臣)” and the dosages, where slight adjustments of

dosage or dosage ratios can drastically alter efficacies. Xiangshu thinking has become an instinctive thinking method and cognitive framework for every TCM practitioners during clinical practice, enabling physicians to harmonize subjective intuition with objective observation through the dialectical interplay of Xiang and Shu, achieving “a state of subject-object unity and human-nature integration” [6].

2.3 The historical status, contemporary value, and existing problems of Xiangshu thinking

In the early formation of TCM theory and thousands of years of clinical practice, Xiangshu (phenotype-numerology) thinking has served as the foundational tool for TCM to comprehend the physiological structure and functions of the human body, the laws of disease occurrence and development, the properties, effects, and the mechanisms of Fufang and Fangji compositions and applications. Xiangshu thinking is the intellectual source of vitality that formed TCM's unique system of theory and sustained its clinical efficacy for thousands of years. It integrates the essence of traditional culture wisdom, enabling TCM theory to go beyond the scope of clinical medicine and further understand the laws of the life cycle, the principles of nature, and the way of creation. This makes TCM forward-looking and transcendental, and it is still being verified and validated by modern life science today.

Based on the concept of “the unity of heaven and man”, TCM has constructed a phenotype-numerology model that integrates human physiology, pathology, and the spatiotemporal relationships, including macro-, meso-, and micro-scales. The macro-scale is the annual cycles in the scale of years, including the 60-year cycle law of Jiazi (甲子) calendrical rhythm. The meso-scale is the monthly cycles in the scale of months, encompassing the rotation of the 4 seasons and the 24 solar terms. The micro-scale is the diurnal cycles in the scale of days, including the Ziwu Liuzhu theory of the 12 two-hour periods (midnight-midday ebb flow) and the 50-circuit theory of Qi circulatory rhythm within a day-night cycle. However, many mysteries remain unsolved and need to be explored today. For example, does the 60-year cycle law of Jiazi calendrical rhythm universally and stably exist? What is the molecular mechanism of the 50-circuit theory of nutrient Qi and defensive Qi circulatory rhythm in the nutrient-defense theory? At the same time, the phenotype-numerology model of “the unity of heaven and man” still has many shortcomings, such as being relatively primitive, lacking objectivity, standardization and quality control, and lacking reliable clinical and experimental verification. In clinical practice, the application of Xiangshu models for diagnosis and treatment relies heavily on personal perception and intuition of individual TCM physicians, resulting in limited reproducibility of

therapeutic effects and curative outcomes, which restricts the overall development of TCM.

In the digital age, a mission imperative for contemporary TCM practitioners and innovators is to leverage big data and AI technology to inherit and develop TCM Xiangshu thinking, break the existing pattern of TCM, implement the large-scale phenotype-numerology, i.e., the “unity of heaven and man” model of TCM, and achieve the digital transformation of TCM. The TCM digitization will address its inheritance and developmental bottlenecks, enhance the interpretability and transparency of TCM theory and the repeatability of clinical curative effects, and enable TCM, which originated from phenotype-numerology Xiangshu thinking, to stand firm in the forest of the times and remain a vital and respected discipline in the modern scientific landscape.

3 The current application of digits in TCM: the concept and practice of TCM digitization

3.1 Challenges for TCM in the digital-intelligent era and the transformation path

The essence of the big data era is to discover new knowledge through the exchange, integration, and analysis of massive data, thus bringing opportunities, drivers, and engines for the development of various industries [31]. The big data era and TCM digitization are mutually reinforcing and complement each other, and are bound to exert profound impacts on the expression and service capabilities of TCM. This synergy will catalyze novel developmental trends and unleash significant productive potential. In recent years, with the booming development of generative AI large language models, represented by ChatGPT, which has rapidly evolved from the scientific and technological forefront to daily life and brought extensive changes to many industries, triggering transformative shifts across numerous sectors. These advancements have propelled productivity in the big data era to new heights. The application of generative large language models in TCM research and clinical services has swiftly emerged as a focal point in the field, with over a hundred enterprises currently engaged in “AI + TCM” initiatives [32]. China's first integrated TCM large model, Qihuang Wenda (岐黄问道), was launched and put into use in September 2023 [33]. Numerous research institutions and technology companies are continuously developing and optimizing large models of TCM for preliminary diagnosis, initial consultation, and health advisory services, underscoring the vigorous momentum and rapid development trend of digital intelligence in TCM.

Medical AI has higher requirements for interpretability and security due to the particularity of its application field. An analysis of the current TCM digitization efforts reveals three persistent problems: the quality of data is

not high, the data standard is missing, and the data utilization is not enough. These problems have become the threshold to limit the current high-tech information technology to intervene in TCM practice. The traditional Xiangshu thinking of image acquisition and operation has laid the foundation for TCM digitization. To advance this paradigm and complete the digital transformation of

TCM in the new AI era, it is necessary to start with the digitization and informatization of TCM clinical practice (Figure 2). The high-quality data link for the entire process of disease treatment should be established. The real-world TCM diagnostic and evidence-based medical data should be collected and utilized to unlock the value of TCM datasets.

A. Objectification of TCM clinical imaging

**Scale + diagram + TCM examination information collection platform
(independent research and development)**

Scale of allergic rhinitis

程度	轻	中	重
1分	1-2	3-4	5-6
2分	7-8	9-10	11-12
3分	13-14	15-16	17-18

Bristol stool classification



Tongue image acquisition



B. Standardization of TCM clinical data

**Information collection standardization +
natural language processing + term mapping**

Handwritten medical records
→ multimodal electronic
medical record storage



TCM terminology database + knowledge graph + ontology

- Personalized free text, mixed with modern and classical Chinese
- Irregular synonymous expression
- Special TCM free text

寒邪内阻证 症状:
腹痛拘急, 遇寒痛甚,
得温痛减, 恶寒身痛,
手足不温, 口淡不渴,
舌质淡, 苔白腻, 脉沉紧。

大便干 津亏
大便干结 津亏
大便干结难下 津亏
大便干燥 津亏
大便困难 津亏
大便秘结 津亏
大便黏滞 湿热
大便黏滞不爽 湿热

发易脱落
毛易脱落
面部皮肤油脂较多
平素面垢油光
肌肤干或甲错
皮肤偏干
平素面色晦黯
皮肤偏黯或色素沉着

Foundation of informatization

Figure 2 The current digital application of TCM: objectification → standardization

Clinical medical records are precious materials to record the phenotypic manifestation (Xiang) of TCM, and serve as invaluable resources for TCM inheritance and clinical research. However, there were two critical issues in the TCM field. On one hand, many senior TCM Masters (国医大师) and renowned veteran TCM physicians, who are in urgent need of inheritance, have only handwritten medical records, which makes the efficiency of collecting, sorting, saving, learning, transmitting, and inheriting difficult to meet the requirements of the rapid development of TCM modernization. On the other hand, conventional TCM medical records differ significantly from medical records of modern medicine in structure, including specialized TCM terminology, a blend of classical Chinese and modern vernacular, and a lack of consensus-driven TCM terminological frameworks. Existing medical informatics tools, developed based on modern medical knowledge, lack corresponding semantic recognition and translation capabilities tailored to TCM theory and terminology. Thus, it is difficult to use directly in the informatization and standardization of TCM medical records, which is also the reason for the suboptimal quality and underutilization of TCM data. In addition, TCM's Quxiang often relies on the personal experience of individual TCM practitioners and lacks objective qualitative or quantitative standards. The same or similar descriptions may correspond to different pathophysiological phenotypes. This further exacerbates the difficulty of

improving and utilizing the quality of TCM data. This subjectivity also impedes clinical quality control, undermines the internal consistency of evidence-based clinical TCM research, and complicates and restricts the systematic sorting and verification of the characteristics and advantages of various schools of TCM in terms of inheritance. So, if TCM can achieve the objectivity and standardization of “image acquisition” for TCM diagnostic information, how to process the collected phenotypic manifestations of TCM digitally remains a critical challenge. This constitutes the foundation of the TCM big data knowledge project “From Digits to Intelligence” [34].

The author summarizes the transformation pathways for TCM digitization into five hierarchical levels. First, objectification, that is, the representation of the number of images and the objective recording of clinical data, which constitutes the basis for standardization. Second, standardization (Figure 2), that is, the application of uniform criteria for clinical phenotypic acquisition and practice, which is the basis for the informatization of TCM. Third, informatization (Figure 3), that is, the conversion of TCM knowledge into a computer-readable and usable format, which is the premise of the TCM knowledge transformation. Fourth, transformation, that is, the accurate representation of the logic of TCM knowledge (Figure 4), which is the basis for the intelligence of TCM. Fifth, intelligization (Figure 5), that is, the culmination

TCM clinical corpus: Q&A corpus of TCM Master's disease diagnosis and treatment

- From specialized diseases
- Using medical records + conversations as resources
- Establishing the relation between TCM thesaurus and terminology mapping
- Grab real consultation keywords
- Experience of specialized disease diagnosis and treatment, label the constitution-disease-Zhenghou-Fangji (prescriptions) in question and answer



Figure 3 The current digital application of TCM: informatization (an example of the construction of clinical corpus of TCM using the Q&A corpus of TCM Master's disease diagnosis and treatment for informatization)

- Based on the experience of specialized disease diagnosis and treatment, label the constitution-disease-Zhenghou-Fangji in question and answer
- Using informatics strategies to form a practical corpus of questions and answers for the diagnosis and treatment of TCM Masters

Replicable schema
Practical corpus

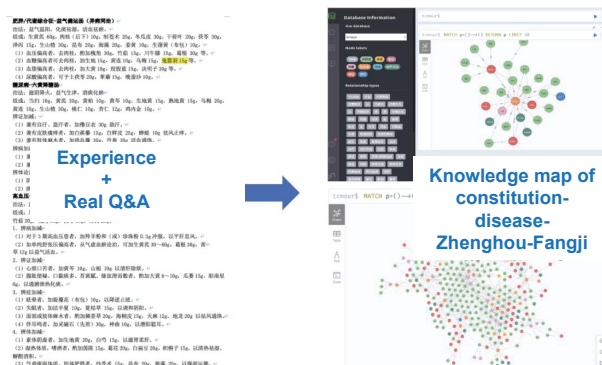


Figure 4 The current digital application of TCM: informatization → knowledgeable TCM (an example of corpus transformation as a replicable constitution-disease-Zhenghou-Fangji knowledge map)

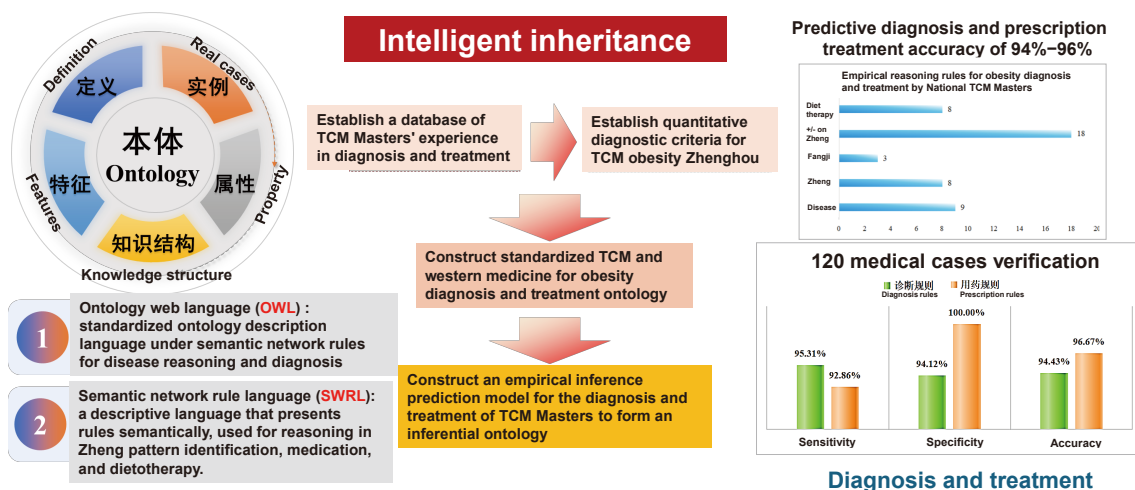


Figure 5 The current digital application of TCM: knowledge → intelligence

Ontology: for a specific field, terms, concepts, and structured terminology sets for relationships between concepts. Standardized and comprehensive knowledge representation of diagnosis and treatment experience through ontology construction. Construct an empirical reasoning prediction model for diagnosis and treatment, and establish an inferential ontology.

of the preceding stages, manifesting as safe, accurate, and interpretable AI-driven TCM systems. Only through the gradual completion of the first four levels can we reach the intelligence level. The safe, accurate, interpretable, and intelligent TCM systems represent the delivery of high-quality, universal, and fast TCM service and the ultimate realization of the digital transformation of TCM.

3.2 Digital TCM physicians: digitization research on TCM constitutions

We have carried out a series of studies on clinical and basic application of TCM constitution theory along with the above-mentioned five levels. We have implemented a series of work in the objectification of “Quxiang (取象),

phenotypic image acquisition”, the informatization of “Cunxiang (存象), image storage”, the intelligent inheritance, and the intelligence of application, thereby established fundamental electronic systems, informatics tools, and intelligent models for the transformation of TCM digitization.

Regarding the objectification and standardization of phenotypic acquisition, we first integrated multiple classic disease/symptom-specific scales into clinical consultations to quantitatively record the symptoms and disease severity of patients. For example, easy-to-understand graphic methods such as Faces Pain Scale-Revised (FPS-R) [35, 36] and Bristol Stool Form Scale (BSFS) [37] are used to achieve clinical phenotype grading. Internationally recognized standardized scales, including the Pittsburgh Sleep Quality Index (PSQI) [38] and Generalized Anxiety Disorder (GAD) Anxiety Scale [39], were utilized to achieve qualitative and quantitative objective collection of disease data (Figure 6). We independently developed a high-precision synchronized electrocardiogram-pulse

wave-respiratory wave acquisition device in line with modern physiological understanding, complemented by tongue-face image capture equipment (Figure 2). This system enables objective recording of TCM observational and palpatory diagnostic phenotypical observations, substantially improving clinical data quality and laying the foundations for improving data utilization.

In the standardization and informatization of “Xiang” storage, our team independently developed a full-chain information collection system for TCM examination and diagnosis (Figure 7). The system takes the quality control of consultation as the first consideration and integrates multimodal data from the entire process of TCM diagnosis and treatment. It features standardized fixed outputs for routine consultation items with error-prevention through fixed character types, and incorporates over ten disease-specific scales. The above self-developed image acquisition devices were connected in series to form an integrated process with a workflow encompassed “modularized consultation scale → objective phenotypic (Xiang)

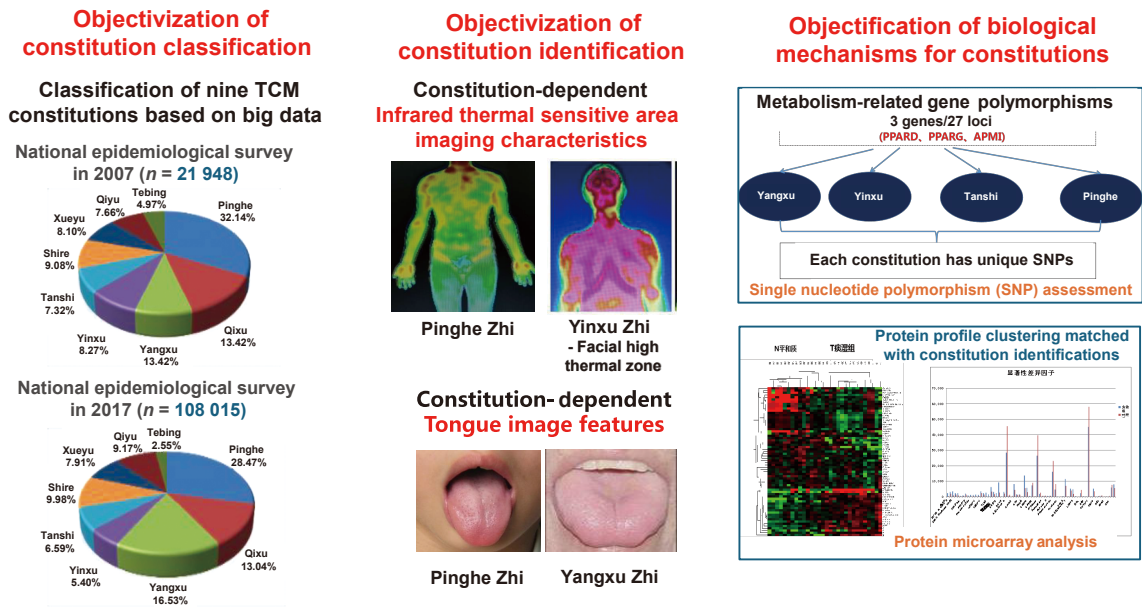


Figure 6 Digitization of TCM constitution: objectification

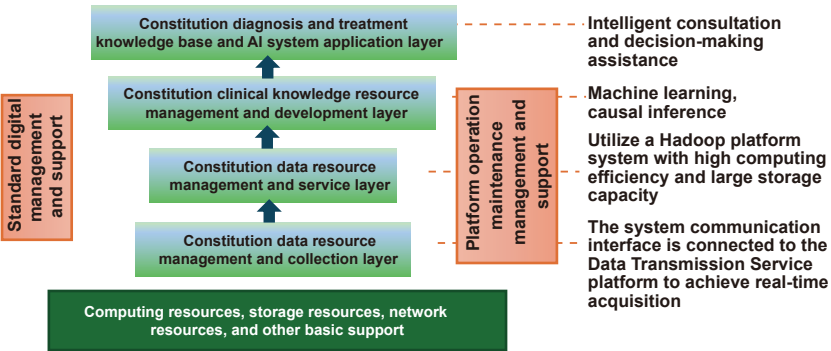


Figure 7 Digitization of TCM constitution: informatization

Informatization of constitution identification is relied on the big data platform of constitutions, which provides efficient and standardized data collection and service.

acquisition via scales + imaging → synchronized storage of handwritten/electronic medical records → integration and storage of multimodal personal clinical data”. This system solves the problem that the existing electronic medical record system is difficult to collect and store the multi-modal “image” of TCM objectively. This also assists TCM physicians to realize the real-time collection and integration of the whole process and all-round comprehensive diagnostic information of TCM, and offers both multi-user clinical observation configurations and independent practitioner modes. The generalization and application of the full-chain information collection system for TCM examination and diagnosis have become an important guarantee for improving the quality and utilization of data.

To computerize the knowledge of TCM, we cut into the characteristic sets and terminology databases of TCM constitutions, took the classical texts of TCM constitutions as the original corpus source, and used natural language processing technology to capture automatically the effective description segments (Figure 8). The independent characteristics of constitutions were obtained through automated word segmentation and expert annotation. The computable constitutional knowledge triplets were formed via semantic analysis. The characteristics of each of the nine constitutions were generated as a

visualized form of maps. The synonym/homograph feature mapping was established and the correlation between constitutional characteristics was identified through expert annotation and coordinated informatics modeling. The meta-knowledge of constitutional characteristics database was ultimately constructed. Subsequently, the internationally recognized Human Phenotype Ontology (HPO) [40], human disease classification database Disease Ontology (DO) [41], and Gene Ontology (GO) [42] were selected, with constitutional characteristics as the core hub, respectively, to establish the connection between TCM constitutional characteristics and modern medical clinical phenotypes, diseases and genes/molecules/pathways. Finally, a mapping relationship between TCM constitutional characteristics and modern medical terminology of clinical phenotypes, diseases, and gene/molecular/pathway networks was established. This mapping framework between TCM constitution theory and modern medical terminologies/knowledge bases provides standardized knowledge resources and tools for “constitution-disease correlation” research and clinical practice, forming the foundation for the intelligence of TCM based on Yunshu Tuixiang (运数推象, operation of digits and inference of images) or “phenomenological deduction through numerological modeling”.

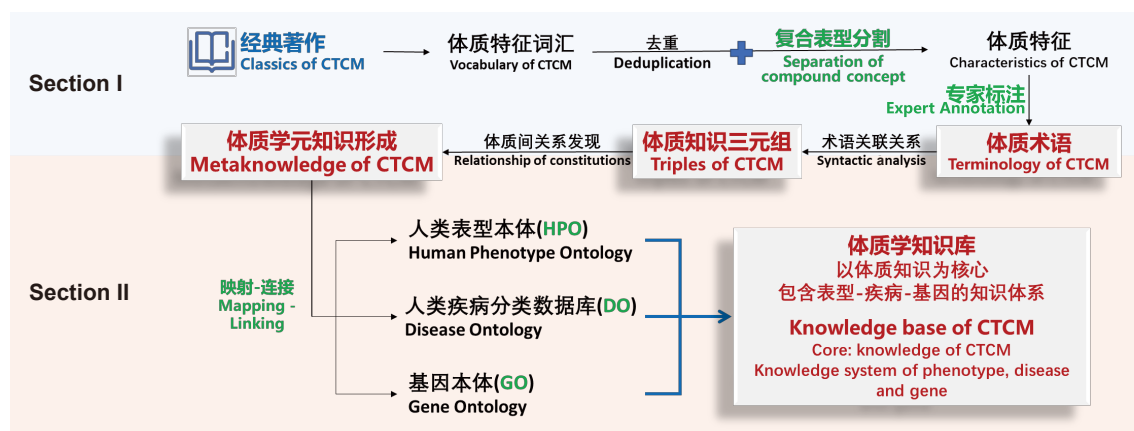


Figure 8 Digitization of TCM constitution: informatization + knowledge

TCM Constitution Knowledge Database: informatization of TCM constitutions; connected with the internationally accepted modern medical terminology and knowledge bases; established informatics foundation for the application of integrated Chinese and western medicine and international extension of TCM constitutions.

In terms of intelligent applications, our team employed database technologies, data analytics technology, AI technology and other means to integrate previous achievements in constitutional research. A digital TCM constitution platform for research, healthcare, and education was developed through incorporating multidimensional constitutional characteristics including infrared thermal imaging, constitution identification scales, etc., equipped with intelligent retrieval, analysis, recommendation and other application functions (Figure 6).

Building upon this foundation, the “Digital TCM Practitioner” WeChat mini-program was further created. Using AI algorithms for multimodal feature analysis, it constructs human digital twins through mobile phone-based tongue-face imaging and question-answer information, generating TCM constitution reports with dynamic monitoring capabilities. At the same time, empowered by enhanced constitution identification algorithms, it provides online health consultation services, professional references for constitution-disease relationships, and

intelligent tools for personalized, proactive health management based on constitution identification and preventive treatment (Figure 7).

In addition, the inheritance of the academic expertise from TCM Masters and veteran practitioners is one of the most urgent tasks in the modernization of TCM, and it is also one of the best adaptation scenarios for the intelligent “phenomenological deduction through numerological modeling”. Based on our previous work, we took the author’s innovative inheritance of obesity diagnosis and treatment experience as an example to explore new models of intelligent inheritance. Specifically, we combined the diagnosis and treatment videos of the National TCM Masters with the clinical medical records, supplemented the text information of the medical records through the doctor-patient question and answer information, and established the obesity diagnosis and treatment medical records information database of the National TCM Masters (Figure 5). We then conducted qualitative and quantitative studies on diagnostic criteria for obesity patterns to develop quantifiable diagnostic standards reflecting the National TCM Masters’ clinical reasoning. Subsequently, we implemented ontological modeling to achieve a structured knowledge representation of the National TCM Masters’ obesity management experience, while incorporating multiple modern medical guidelines and standards. Together with the experience of the National TCM Masters, we constructed the knowledge storage and querying in the integrated ontological framework for obesity diagnosis and treatment. Based on this ontology, we further utilized the semantic web rule languages to construct the inference rules for constitutional differentiation, disease identification, Zhenghou pattern differentiation, and treatment formulation, establishing a reasoning-prediction model for obesity management decisions. Through the example verification of the clinical medical records of the National TCM Masters, it is proven that the ontology represents the accuracy of the National TCM Masters’ obesity diagnosis and treatment experience. Additionally, the personal characteristics of the National TCM Masters’ diagnosis and treatment experience are proven by the way of ontology, so as to realize the inheritance of the National TCM Masters’ obesity diagnosis and treatment experience from knowledge representation to knowledge reasoning. At the same time, it provided practical tools for the inheritance of academic experience and medical education.

4 The future of TCM towards digitization: digitization promoting the transformation and upgrading of TCM

4.1 Application scenarios facing the digitization of TCM

The digital technologies in the era of big data and informatization have brought great opportunities for the inheritance and innovation of TCM, created a new track

for the digitization of TCM, and fostered an emerging ecosystem for digitized TCM. The next objective of TCM digitization lies in creating new quality productive forces. To carry out multidisciplinary cross-integration combined with large model technology, strengthen digital empowerment, obtain clinical decision-making supported by big data, and promote the digital transformation of TCM are the focus points of digital TCM development. The crucial approaches to promote the development of clinical modernization of TCM and the integration of TCM and western medicine include (i) maximizing the value of digital, informational, and intelligent technologies; (ii) leveraging health care big data resources to efficiently obtain evidence-based real-world data of the TCM efficacy; (iii) combining highly shareable and computable knowledge with powerful iterative algorithms to achieve multidimensional knowledge integration and multi-modal data analysis for complex TCM medical reasoning; (iv) deciphering the idea of the holistic view of TCM; (v) obtaining evidence for the pathophysiological mechanisms of the superior diagnosis and treatment links of TCM; and (vi) promoting the integration of TCM and western medicine (Figure 9). The State Council’s Notice on Implementation Plan for Major Projects of Traditional Chinese Medicine Revitalization and Development (Guobanfa [2023] No. 3) emphasized several key initiatives, including “constructing national key laboratories for the interdisciplinary integration of TCM-related disciplines” “establishing an AI technology application platform for ancient TCM books and a TCM knowledge service system” “developing digital auxiliary diagnostic equipment of TCM, intelligent equipment for TCM characteristic therapy, and modern equipment for TCM treatment of pre-disease” and “developing TCM quality intelligent identification and control engineering technology and equipment research” [43]. The focus of the future digital development and application of TCM includes but is not limited to the six aspects of platform construction, knowledge inheritance, ancient book utilization, service innovation, equipment development, and industrial transformation.

First, in terms of platforms, it is necessary to strengthen the construction of digital infrastructure and platforms, build national key laboratories for the interdisciplinary integration of TCM-related disciplines and consolidate the basic platforms for TCM digitization. To carry out cutting-edge research on basic science in TCM modernization, the Ministry of Education and the National Administration of Traditional Chinese Medicine have established several national key laboratories in recent years. These include the State Key Laboratory of Natural and Biomimetic Drugs at Peking University, the State Key Laboratory of Pharmaceutical Biotechnology at Nanjing University, and the State Key Laboratory of Natural Medicine Active Substances and Pharmacodynamics at

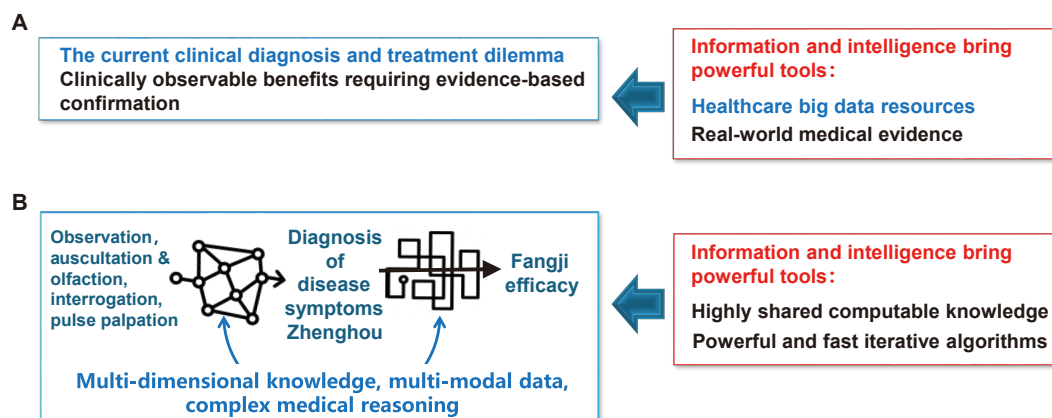


Figure 9 The future of TCM going towards digitization: what should big Chinese medicine practitioners do?

A, it is urgent to obtain evidence of the pathophysiological mechanism of the superior diagnosis and treatment of TCM to promote the integration of TCM and western medicine. B, it is urgent to enhance the ability to decipher the holistic view of TCM.

China Pharmaceutical University. The General Office of the Hubei Provincial People's Government has established the Hubei Laboratory of Traditional Chinese Medicine (Shizhen Laboratory) through the implementation of the major project of the revitalization and development of TCM, and brought together the advantageous platforms and disciplines in the field of TCM to develop the life and health industry. Future efforts should leverage these established platforms to promote interdisciplinary integration and drive transformative innovation in TCM research paradigms.

Second, in terms of knowledge inheritance, it is necessary to intensify efforts to develop digital technologies that facilitate the preservation and transmission of renowned veteran TCM practitioners' academic thoughts and clinical experience. The 12th Five-Year National Science and Technology Support Program "Clinical Experience and Academic Thought Inheritance Research of Veteran TCM Practitioners" project established China's first open-access national service platform for famous veteran TCM experts open to the society. This platform integrated research achievements from previous national projects of the 10th and 11th "Five-Year Plan", brings together the research results of famous TCM physicians' inheritance, and has built five premium databases, including typical classic medical case repository, effective prescription libraries, diagnosis and treatment technology libraries, health care libraries, and expert development pathway archive road to success libraries. This platform provides services for experience inquiry, learning, and social services of famous TCM physicians. Future initiatives should focus on enhancing inheritance efficiency through multidisciplinary technologies while maintaining an emphasis on core traditional knowledge.

Third, in terms of ancient book utilization, it is necessary to establish an AI-powered application platform and a TCM knowledge service system for ancient TCM books, promote the digital mining of ancient TCM books, and

create digital service application products for ancient TCM books. The current TCM digital intelligence platforms such as "CloudPhar (星斗云, <https://www.taslypharma.com/kygx.jhtml>)" and "Ancient & Modern Medical Case Cloud Platform (古今医案云平台, <http://yiankb.com>)" all utilize multidisciplinary information mining technology to explore mechanisms of herbal medicine and Zhenghou patterns based on classical ancient books. In addition, the recently born "Qihuang Wendao (岐黄问道)" "Shennong TCM Big Model (神农中医药大模型)" "Zhongjing TCM Big Language Model (仲景中医大语言模型)" "Huangdi Model (黄帝模型)" "Materia Medica Model (本草模型)" and other TCM big models use their enhanced knowledge comprehension capabilities to provide the TCM industry with new options for multi-scenario intelligent services. In the future, as a representative of the reform of TCM, the big model of TCM will continue to facilitate the understanding application of TCM knowledge and to empower the inheritance of TCM.

Fourth, in terms of service innovation, it is necessary to explore novel models of TCM data circulation in service innovation to achieve the digital reengineering of TCM service processes and innovate new formats of TCM services and healthcare delivery. The "Digital TCM Practitioner" system, jointly developed by our research team and Tianjin University in April 2024, implements mobile phone-based remote consultation, intelligent analysis, report issuance, and online consultation through the "Internet + TCM" model. This innovation enables digital circulation and restructuring of TCM data, realizing integrated online-offline diagnosis and treatment models, while unleashing data value. In the future, we should further use information technology to connect the data systems of hospitals, communities, and households, to give full play to the TCM's preventive and therapeutic advantages, and to construct novel integrated healthcare ecosystems.

Fifth, in terms of equipment development, it is necessary to develop digital auxiliary diagnostic equipment of TCM, intelligent equipment for characteristic TCM therapies, and modern TCM preventive healthcare instruments. The first domestic digital TCM robot “SY-2 Research-Type Digital TCM Meridian Treatment Robot” has obtained the first “Innovative Medical Device” registration certificate in TCM treatment. Relying on the basic theory of TCM, the robot integrates flexible robotics, human body three-dimensional (3D) visual tracking, deep learning, and force perception technology to achieve AI + traditional acupoint manipulation therapy. Future intelligent TCM equipment should enable comprehensive smart management of disease diagnosis, monitoring, and regulatory conditioning through full-process closed-loop services, bringing digital “family physicians” into communities and households. The early domestic development of TCM physician robots holds the potential to break down the foreign monopolies and significantly contribute to TCM revitalization.

Sixth, in terms of industrial transformation, TCM digitization should promote the transformation and upgrading of the TCM industry through integrated digital analysis of disease-Zhenghou pattern-Fangji-herb relationships, creating new paradigms of digital Fangji and intelligent herbal medicine. This involves research on engineering technology and equipment for intelligent identification and control of herbal materials quality, including intelligent processing control for decoction pieces, digital core manufacturing processes for Chinese patent medicines, and quality assurance systems for herbal production. The “TCM Inheritance Assisting System Software (TCMISS)” jointly developed by the Institute of Traditional Chinese Medicine of the China Academy of Chinese Medical Sciences and the Institute of Automation of the Chinese Academy of Sciences uses AI, data mining, network science, etc. to analyze diseases and related TCM prescriptions, to obtain common symptoms, Zhenghou patterns, core drug combinations, and new Fangji prescriptions. At present, there are still serious problems in the quality of Chinese herbal medicines and decoction pieces, such as adulteration, dyeing and weight gain, non-standard improper processing, excessive heavy metal/pesticide residues, etc., and it is urgent to introduce modern intelligent identification and monitoring technology to ensure the production of TCM medicinal herbs and the preparation of decoction pieces, thus to enhance production standardization of TCM and boost the industrialization of TCM.

4.2 Future prospects of digitization of TCM constitutions

As previously discussed, TCM constitution has completed a series of works in the objectification, standardization,

informatization, knowledge, and intellectualization of clinical and scientific research. In the future, studies of TCM constitution will further build a big data platform system of TCM constitution with a clear structure, full-dimensional coverage, and sustainable operation, including the National TCM Constitution-Based Preventive Healthcare Network Platform, big data application analytics platform, monitoring and early warning platform, and multi-level and multi-dimensional management platform (Figure 10). Our key initiatives will focus on developing constitutional identification models and panoramic mapping for Chinese populations, and establishing AI models for the nine constitutions. We will create a nine-constitution-guided analytical framework to conduct an in-depth investigation of latent correlations among different constitutions using multi-feature fusion analysis and implicit relationship mining technologies. We will integrate the multidimensional information and imaging data of individual characteristics of constitutions to generate comprehensive and multi-angle health portraits and profiles, and ultimately form a constitutional panorama. Based on the theory of TCM constitution, the characteristics of nine constitutions are studied and digitized, and intelligent algorithms are used to accurately interpret individual constitutions. An intelligent decoding system will be built to enable users to easily understand their constitution types and provide guidance for personalized health management. Individual users may gain a deep understanding of their constitution and establish a personalized “Chinese constitution panorama” for practical application through an interactive interface.

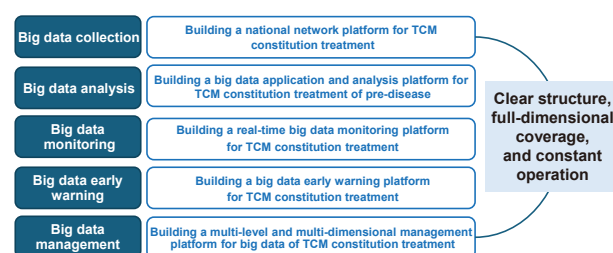


Figure 10 The future of TCM going towards digitization: the digitalized intelligence of TCM constitution

The breakthroughs in key technologies for digitization and intelligent decoding of TCM constitutions will facilitate the creation of a “Chinese Constitutional Panoramic Map” tailored to the genetic heritage and constitutional characteristics of Chinese populations. These innovations will pioneer new paradigms for national active health management and disease prevention and treatment, open up a new world of intelligent computing-empowered TCM modernization, and contribute Chinese wisdom and solutions to the Healthy China Initiatives.

4.3 Inclusive acceptance of diversity in scientific research paradigms

There exists inherent diversity in scientific research, and choosing a research model suitable for TCM will be more conducive to the innovation of TCM (Figure 11). The classical medical research model derives experience through research on literatures and summarization of clinical medical records, while the modern medical research model forms a physical route from experience or empirical observations to physical explanations, forming the so-called “physical route”. The first abstraction of TCM was rooted in *Yijing*, which abstracted the relationship between natural images/phenomena (Xiang) and human health as Yin and Yang (阴阳), Wuxing (五行), Wuyun Liuqi (五运六气), etc. In addition to the classical route and the physical route, it is also possible for TCM to develop its unique route by introducing multidisciplinary integration, that is, a leap from experience to digital. The second revolution of TCM has arrived, that is, the change based on multi-disciplinary intersections. By linking TCM to mathematics through the abstraction of mathematical models, we can rise directly from experience to digits, seeking purely rational proofs from mathematics abstract modeling, empirical knowledge ascends directly to digital expression, seeking rational verification through mathematical frameworks. At present, TCM is undergoing the second abstraction. With the help of mathematics and AI, it is standardized and modeled to form laws and theorems and discover the constants of TCM [44]. The innovation of TCM needs to take TCM as the cornerstone, and extensively intersect and integrate TCM with mathematics, computer science, biology, and complexity science research to produce large-scale innovation. But, it is also necessary to strictly grasp the scale of integration and balance, understand the ambiguity and intuitive thinking in the theory of TCM, and “transformation is not transgene”. TCM innovation also requires maintaining its theoretical essence.

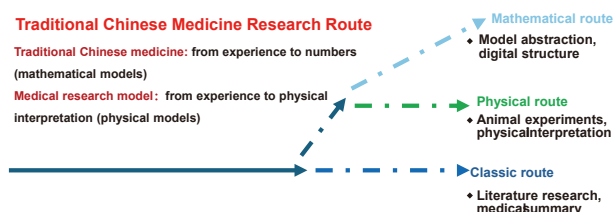


Figure 11 Future of TCM going towards digitization: TCM research models

TCM links to mathematics through the abstraction of mathematical models, we can rise directly from experience to numbers, seeking purely rational proofs from mathematics.

Multidisciplinary cross-fertilization will undoubtedly bring new opportunities to the field of TCM. In the process of TCM digitization, maintaining the essence and

laws of TCM principles remains paramount. Big data and big models have huge advantages, but they cannot yet explain the ambiguity and uncertainty contained in TCM. Data are the primary information directly presented to people, and mastering enough necessary data is a necessary prerequisite for drawing scientific conclusions, but the role of intuition and experience in judgment cannot be ignored. Therefore, in the transformation of TCM digitization, it is also necessary to handle the six philosophical relationships of “data and judgment” “measurable and unmeasurable” “precision and chaos” “necessity and accident” “correlation and causality” and “complexity and linearity”.

Data support is helpful for judgment, but judgment cannot rely solely on data. For example, TCM physique can be identified by objective criteria and data of scales, but it is equally accurate to identify physique by relying on clinical experience, and may contain other effective criteria for individual precision and characterization. Another example is the famous “Simpson’s paradox” in statistics. The same data may lead to contradictory conclusions when answering the same question under different processing conditions. In other words, if the data lacks thinking and judgment about its substantive meaning, it cannot produce value that is truly in line with objective reality. This is the importance of “judgment” based on empirical and theoretical thinking to scientific interpretation. “Data” and “judgment” are not completely opposed, nor can they be separated.

Science is constantly evolving, so there are many “unmeasurable” things in scientific research. The “measurable” and “unmeasurable” in scientific research have always been in dynamic change. While measurable data constitutes essential productive elements in the big data era, technological advances progressively transform unmeasurable phenomena into measurable “states”. The concept of “state” encompasses systematic, observable, and identifiable conditions, trends, situations, and characteristics that manifest through informational expressions, with diverse descriptions of state variables. It has become a consensus to use the scientific model of complex systems to study, and it has become an inevitable trend to characterize health with the concept of “state” in systems science. From this, we propose the concept of “health state”, that is, the comprehensive state of the human body’s morphological structure, physiological state, and ability to adapt to the external environment within a certain period [45]. A health state can reflect the state and posture of health. TCM health status identification methods are usually based on four dimensions, i.e., physiological, genetic, psychological, and adaptability dimensions. It incorporates 12 measurable assessment methods of TCM constitutional scale assessment, immunogenetic profiling, psychological characteristic assessment, health status scale assessment, macroscopic characteristics

assessment, sleep physiological assessment, biochemical index assessment, metabolomic characteristics assessment, mRNA expression profile characteristics assessment, core solo polymorphism assessment, and protein expression characteristics assessment. Health-related quality of life measurement, health state scale evaluation, macroscopic feature analysis, sleep physiology monitoring, biochemical index testing, metabolomic profiling, mRNA expression mapping, single nucleotide polymorphism analysis, and protein expression characterization. While these measurable parameters exist, immeasurable aspects persist in scientific inquiry, as exemplified by Heisenberg's "Uncertainty Principle". The *Suwen·Yinyang Lihe Lun* (《素问·阴阳离合论》), clutch theory of Yin and Yang) also mentioned that "the number of Yin and Yang people can be ten, inferred can be hundreds, and the number can be thousands, inferred can be tens of thousands, and the number of tens of thousands is innumerable, but it needs to be one" [17]. So the unpredictable part is also worthy of attention, showing the importance of acknowledging unmeasurable dimensions.

The dichotomy of "precision and chaos" is also a pair of opposing relationships that cannot be ignored. Scientific research requires accurate data to provide support to draw scientific conclusions. If persuasive evidence cannot be provided, it cannot be recognized by the academic community and improve credibility. However, we need to accept and respect the unknown and unfathomable truth of science, which is the "chaotic land" of scientific research, and exists at the same time as the "precision" of science. Chapter 21 of the *Daodejing* (《道德经》), or *Tao Te Ching*) highlights the coexistence and interweaving of chaos and precision: "The Dao, is vague and elusive. Elusive and vague, within it there is form. Vague and elusive, within it there is substance. Deep and obscure, within it there is essence. This essence is supremely real; within it lies trustworthiness" [46]. Meanwhile, *Zhuangzi·Ying Diwang* (《庄子·应帝王》) presents the famous creation allegory of the death of Hundun (混沌, chaos). The two Emperors of the South Sea and the North Sea, Shu and Hu, wished to repay the virtue of Hundun, the ruler of the center. They observed, "All beings have seven orifices for seeing, hearing, eating, and breathing, yet he alone has none. Let us try carving them for him" [47]. They bored one hole each day, and on the seventh day, Hundun perished. This parable powerfully underscores the necessity to respect chaos rather than pursue excessive precision. Inspired by the phenomenon of chaos, Hideki Yukawa, a laureate of the Nobel Prize in Physics in 1949, proposed the "meson theory" of the nuclear force in 1935 [48].

"Necessity and contingency" describe the frequency of phenomena, and necessity reflects objective regularity. Scientific research reveals the trend of things from the appearance of disorder. Therefore, necessity is undeniable, but we should not ignore individual cases. The book

Happy Accidents: Serendipity in Modern Medical Breakthroughs [49] introduces the accidental discoveries in medicine since the 20th century, including antibiotics, X-rays, antidepressants, chemotherapy drugs, *Helicobacter pylori*, cervical smear tests, genes, stem cells, etc. Through interviews with laureates of the Nobel Prize in Medicine and winners of other prestigious awards, the book illustrates how these serendipitous discoveries have promoted the progress of science. The accidental discovery Chengjiang biota (澄江生物群) at Maotianshan (帽天山) provides a complete display of the early Cambrian marine communities and ecosystems, provides precious evidence for the study of the origin, evolution, ecology, and other theories of life in the early earth for 53.70 million years. This serendipitous discovery ignited a great starting point for the exploration of life. The "case study method" in medicine is the whole process of continuously investigating an individual, a group, or an organization over a long period of time to study the development and changes of its behavior, so as to obtain definitive evidence. Therefore, we value necessity, but we do not rule out that accidental results can be generalized to general situations and applied in subsequent practice.

In medical research, it is usually necessary to answer the question of "association and causation". Association solves the question of "what", and "cause and effect" answers the question of "why". TCM uses the five elements of "metal, wood, water, fire, and earth" in the human body's "lungs, liver, kidneys, heart, and spleen" to describe the relationship between human organs. After solving the problem of "what", scientific research will pay more attention to the question of "why". Fishbone analysis is an analysis method to find the "root cause" of the problem. Through the path analysis of fishbone shape, the relationship between each sub-cause is displayed.

Things are full of various "complex and linear" relationships. Linear relationships easily reflect the relationships between things and are easier to explain. However, in actual research, there are more nonlinear and complex relationships between things. In clinical practice, various interactive variables and invisible confounding factors will affect the occurrence and development of diseases. These complex relationships also make clinical diagnosis more challenging. TCM research cannot be separated from these six fundamental scientific questions. Only by grasping the above scientific research questions can TCM move forward during the digital transformation.

5 Conclusion

Data can be labeled, recorded, stored, and linked to the world, and information about all human activities can be expressed in the form of data. The new round of scientific and technological revolution and industrial revolution

together constitute digitization, networking, and intelligent development, involving new energy, new manufacturing, new industries, new products, new production factors, new infrastructure buildings, new enterprise organization methods, new business operation models, and new consumption experiences. In this context, the transformation of TCM from digits to digitization will enhance the service capabilities of TCM, create an innovative digital intelligent TCM service platform, and provide native wisdom and adaptive solutions for Healthy China Initiative. By harnessing modern information and intelligent technologies, TCM can seize emerging developmental opportunities, pioneer interdisciplinary integration across medicine, mathematics, and engineering disciplines, establish rapid innovation systems for TCM knowledge and wisdom and chart a high-quality development path that respects TCM's unique characteristics.

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Competing interests

The authors declare no conflict of interest.

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从数字中走来又走向数字——中医数字化的过去、现在与未来

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【摘要】 中医数字化是第四次产业革命背景下的中医学发展必由之路。中医从数字中走来, 原创思维模式蕴涵了“取象运数”的象数思维, 是中医数字化的理论渊源所在。中医数字化应从临床开始, 解决临床资料的电子化问题, 实现标准化、信息化, 并在信息化的基础上知识化, 形成中医知识库。中医数字化的目标是由“数”生“智”, 该过程有赖于医学、数学、工程学等多学科交叉形成合力, 实现中医的数字化与数智化。时代呼唤中医学破除壁垒, 把握机会, 走向数字化, 但又转型不转基因, 避免简单化转换, 而应以科学价值为导向, 借力前沿技术, 提升中医学内涵阐述的深度和广度。中医数字化转型也将提升中医的服务能力, 打造创新性的数字智能化中医服务平台, 为健康中国提供智慧和方案。

【关键词】 中医数字化; 中医现代化; 多学科交叉