Influence of doctors’ perception on the diagnostic status of chronic kidney disease: results from 976 409 individuals with electronic health records in China

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ABSTRACT

Background. The diagnostic status of chronic kidney disease (CKD) and its underlying reasons provide evidence that can improve CKD management. However, the situation in developing countries remains under-investigated.

Methods. Adults with electronic health records (EHRs; 2008–19) in Yinzhou, China were included. The gold standard for CKD was defined as having persistently reduced estimated glomerular filtration rate (eGFR), albuminuria/proteinuria, haematuria or a history of CKD. CKD stages (G1–G5) were defined by eGFR. Clinical diagnosis of CKD in the real world setting was evaluated using International Classification of Diseases (ICD)-10 codes related to primary cause or stages of CKD. The specialty of doctors who administered the serum creatinine (SCr) tests and who made the primary-cause/CKD-staging diagnoses was analysed. The accuracy of CKD-staging codes was assessed.

Results. Altogether, 85 519 CKD patients were identified from 976 409 individuals with EHRs. Of them, 10 287 (12.0%) having persistent urinary abnormalities or labelled with CKD-related ICD codes did not receive SCr tests within 12 months before or after the urine tests. Among 75 147 patients who received SCr tests, 46 150 (61.4%) missed any CKD-related codes, 6857 (35.7%) were merely labelled with primary-cause codes, and only 2140 (2.9%) were labelled with CKD-staging codes. The majority of CKD patients (51.6–91.1%) received SCr tests from non-nephrologists, whereas CKD-staging diagnoses were mainly from nephrologists (52.3–64.8%). Only 3 of 42 general hospitals had nephrologists. The CKD-staging codes had high specificity (>99.0%) but low sensitivity (G3–G4: <10.0%).
Conclusions. Under-perception of CKD among doctors, rather than unsatisfactory health-seeking behaviour or low detection rates, was the main cause of under-diagnosis of CKD in China. Intensification of CKD education among doctors with different specialties might bring about immediate effective improvement in the diagnosis and awareness of CKD.

Keywords: chronic kidney disease, diagnostic status, doctors’ perception, electronic health record, ICD-10 code

INTRODUCTION

Chronic kidney disease (CKD) is a global public health burden because of its high prevalence, low awareness, multiple comorbidities and substantial economic burdens [1–3]. The Global Burden of Diseases study [4] estimated that CKD would be the fifth cause of mortality by 2040. Timely and accurate diagnosis improves not only the awareness of CKD but also the initiation of the long-term integrated management resulting in a better outcome of CKD [5–7]. However, previous studies reported the under-diagnosis of CKD in developed countries [8–11]. The low detection rate of CKD-related tests and a shortage of medical resources were considered as the main causes of under-diagnosis of CKD [2, 10, 12]. Regarding the utilization of healthcare services, the asymptomatic nature of early stages of CKD hinders patients’ motivation to seek healthcare services and the limited health literacy of patients is associated with less efficient use of the service, which together aggravate the low rates of detection and diagnosis of CKD [13–15]. Hence, population-based screening of CKD, patient education and an increase in financial support were recommended to improve the early diagnosis of CKD [2, 3, 16]. However, the feasibility and effectiveness of these strategies in developing countries might be influenced by the disparity of socioeconomic and medical development [3]. Therefore, individualized solutions, which could be modified according to the current diagnostic status and underlying reasons in the less developed regions, were needed. However, the diagnostic status of CKD in developing countries, such as China, which is facing great challenges because of its large population, ageing society and unique socioeconomic status [17], remains unclear.

As to the diagnosis of CKD, the US-based Kidney Disease Outcomes Quality Initiative group proposed the CKD staging system in 2002, which classifies CKD into five stages (G1–G5) from normal to kidney failure according to the levels of estimated glomerular filtration rate (eGFR) [18]. CKD is the cause and consequence of multiple diseases [5, 18, 19]. Hence, the Kidney Disease: Improving Global Outcomes (KDIGO) clinical guidelines for CKD (2012) further developed the staging system into cause, GFR and albuminuria to stress the integrated management of CKD, including primary-cause treatment, kidney function preservation and prognosis prediction [5]. This generated a unique insight into CKD diagnosis, extended the traditional cause- or classification-based diagnosis of kidney disease and emphasized the importance of CKD diagnosis as an independent clinical manifestation.

The International Classification of Diseases-10 (ICD-10) had coded CKD G1–G5 as N18.1 to N18.5, respectively [20]—a notable action to promote the concept of CKD and the staging system into clinical diagnosis [20]. In China, ICD-10 codes have been widely used in healthcare systems. The utilization of primary-cause and CKD-staging-related ICD codes in the real world setting could, respectively, represent the traditional cause-based diagnosis of kidney disease and the specific diagnosis of CKD in daily clinical practice. Based on the laboratory results extracted from electronic health records (EHRs), gold standard for CKD in accordance with the KDIGO-CKD clinical guidelines could be adopted to recognize the patient with CKD. Therefore, this study investigated the diagnostic status of CKD and its underlying reasons in China by evaluating the utilization of CKD-related ICD codes based on 976,409 individuals with EHRs, which span across 758 health and medical institutes during a time period of 11 years in Yinzhou, Zhejiang, China.

MATERIALS AND METHODS

Data source and pre-processing

The process of this study is summarized in Figure 1. This study was conducted based on the Regional Health Information System (RHIS) in Yinzhou. Yinzhou is a district of Ningbo City, Zhejiang Province in China, located 230 km south of Shanghai. By the end of 2019, Yinzhou had a population of 1.42 million, 98% of which has been registered in the RHIS. An EHR in RHIS is the personal health profile including data from the population census and registered health insurance database, health checks database, disease surveillance and management database, outpatients/inpatient electronic medical records (EMRs) database, and charge and claims database. An EMR is the personal medical profile including medical records, laboratory results, imaging results and costs data in clinical institutes [21]. Detailed description of the RHIS has been published elsewhere [21, 22].

Individuals aged ≥18 years and having EMRs in any medical institute from 1 May 2008 to 31 December 2019 were included as candidates in this study. To select eligible candidates, a unique code for each individual was generated according to the person’s ID number, name, gender and date of birth. Using the unique code, data de-duplication and linkage were performed to integrate the EHRs and EMRs of each individual together. After de-duplication, 1,028,254 individuals with EHRs and 10,981,723 individuals with EMRs were extracted, respectively. After data linkage, 976,409 individuals aged ≥18 years with intersecting EHRs were included as candidates in the following analyses (Figure 1).

Focussing on the target population of 976,409 candidates, the following data were extracted from their intersecting EHRs: (i) general demographic data; (ii) medical records containing diagnoses and specialty of doctors; and (iii) urine tests and serum creatinine (Scr) tests. Patients identified as having CKD (described below) but missing diagnosis records or ICD codes within 12 months before or after the CKD-related tests were ultimately excluded (Figure 1).

This study has been approved by the ethics committee of Peking University First Hospital.

Criteria for CKD and staging

Patients with CKD were identified from the population of 976,409 candidates. In accordance with the KDIGO-CKD clinical guidelines (2012) [5], the criteria for CKD were defined as one or more of the following manifestations persisting for 3 months or longer: (i) eGFR <60 mL/min/1.73 m²; (ii) albuminuria: urine albumin-to-creatinine ratio ≥30 mg/g or urine albumin excretion
Criteria for CKD-related ICD-10 codes

The Chinese edition of ICD-10 was used in this study. In this edition, the ICD-10 codes were extended from four to six digits to localize and adapt the Chinese healthcare system. The diagnostic status of CKD was evaluated by analysing the utilization rates of different CKD-related ICD-10 codes.

Primary-cause codes, which indicate the diagnosis of primary cause of CKD, include primary, secondary or congenital kidney disease, maintenance dialysis and being a recipient or donor of kidney transplantation. Because of the inexact causality between some common primary causes of kidney injury (such as Wegener granulomatosis, Sjögren’s syndrome, etc.) and CKD, primary-cause codes were only used to evaluate the quality of CKD diagnosis, instead of the identification of CKD patients. The detailed primary-cause codes and the correspondence between the English and Chinese editions are presented in Supplementary data, Table S1.

CKD-staging codes, which indicate the CKD diagnosis with staging, include: N18.801 CKD, Stage 1 (corresponding to N18.1 in the English edition); N18.802 CKD, Stage 2 (corresponding to N18.2 in the English edition); N18.803 CKD, Stage 3 (corresponding to N18.3 in the English edition); N18.804 CKD, Stage 4 (corresponding to N18.4 in the English edition); and N18.001 CKD, Stage 5 (corresponding to N18.5 in the English edition).

Statistical analysis

Age [mean (standard deviation, SD)], gender (n, %), inpatient/outpatient category (n, %) and proportions of patients receiving SCr tests before and after the publication of KDIGO-CKD clinical guidelines (n, %) were described by each CKD stage. The
utilization rates of primary-cause codes and CKD-staging codes before and after the publication of KDIGO-CKD clinical guidelines were analysed. The specialty of doctors who administered the SCR tests and who made the CKD diagnoses with primary-cause or CKD-staging codes were analysed. Nephrology-related resources in general hospitals, characterized as the accessibility of nephrologists, were analysed. The identification performance of each CKD-staging codes was evaluated in terms of sensitivity, specificity and accuracy using the following formula:

\[
\text{Sensitivity} = \frac{\text{True positive}}{\text{True positive + False negative}} \times 100\%
\]

\[
\text{Specificity} = \frac{\text{True negative}}{\text{True negative + False positive}} \times 100\%
\]

\[
\text{Accuracy} = \frac{\text{True positive + True negative}}{\text{True positive + False negative + False positive + True negative}} \times 100\%
\]

The present computation in the RHIS was based on the Hadoop framework. The computing engine was Spark and the data warehouse was Hive as the support for SQL (The Apache Software Foundation, Wakefield, UK). The accuracy of CKD-staging codes was analysed using MedCalc version 15.8 (MedCalc Software Ltd, Ostend, Belgium).

**RESULTS**

**Characteristics of patients with CKD**

Altogether, 85,519 patients with CKD were identified from 976,409 candidates. The prevalence of CKD in Yinzhou was 8.8%. After excluding the patients missing diagnosis records or any ICD codes, 85,434 patients with CKD were ultimately included. Among them, 10,287 (12.0%) patients having persistent proteinuria or haematuria or labelled with CKD-related codes had no SCR tests within 12 months before or after the abnormal urine tests. Of 75,147 patients who received SCR tests, 85.0% were in early stages (G1 and G2). The age of CKD patients peaked in G3 (G1: 49.0 years; G3: 74.2 years; G5: 62.3 years). Fewer males were observed in this study compared with females (males versus females: 39.6% versus 60.4%). Altogether, 28,967 (38.5%) patients with CKD and showed albuminuria/proteinuria and 32,964 (43.1%) patients showed haematuria. The percentage of patients with albuminuria/proteinuria increased with stages and showed the highest proportion in G5 (54.5%, 68.5%). More outpatients were observed (overall: 47.422; 63.1%) except for patients in G5 (359; 45.2%). The majority of patients with CKD received SCR tests after the publication of KDIGO-CKD clinical guidelines (62,469; 83.1%) (Table 1).

**Utilization of CKD-related ICD codes**

The utilization rates of CKD-related ICD codes were low, especially the CKD-staging codes. Altogether, 46,150 (61.4%) patients who received SCR tests were not labelled with any CKD-related codes. Patients with CKD in early stages were more likely to miss CKD-related codes (G1 versus G5: 66.9% versus 18.1%) (Table 1).

Among the patients labelled with CKD-related ICD codes, 26,857 (35.7%) patients were merely labelled with primary-cause codes, without CKD-staging codes. This indicates that a number of doctors had the capacity to diagnose the kidney disease, however they were lacking the perception of CKD as an independent manifestation. Only 2,140 (2.9%) patients were labelled with CKD-staging codes and 75.0% (1,606) of them were also labelled with primary-cause codes. Of the patients in G1, 32.4% had primary-cause codes and 0.8% had CKD-staging codes. Of the patients in G5, 60.0% had primary-cause codes and 21.9% had CKD-staging codes. Altogether, 2,125 (99.3%) patients with CKD were labelled with CKD-staging codes after the publication of KDIGO-CKD guidelines (Table 1).

**Specialty of doctors who administered SCR tests to patients with CKD**

The majority of patients with CKD visited non-nephrologists and received SCR tests from them. Only 8.9% of the patients with CKD in G1 and 11.8% in G2 received SCR tests from nephrologists. Meanwhile, only 11.7% of the patients in G3 and 21.7% in G4, who have an increased risk of adverse outcomes of CKD [5], received SCR tests from nephrologists. More than 50% of the patients in G5 received SCR tests from non-nephrologists (Table 2).

**Specialty of doctors who labelled CKD patients with CKD-related ICD codes**

Diagnostics labelled with CKD-staging codes were mainly made by nephrologists (52.3–64.8%). Among patients in G1–G4, the diagnoses merely labelled with primary-cause codes were largely made by general internists (46.2–52.3%). This indicates that a number of non-nephrologists had the capacity to diagnose the kidney disease while lacking perception of CKD as an independent manifestation. In addition, 19.9–23.7% of patients in G1–G4 merely labelled with primary-cause codes were diagnosed by nephrologists, indicating the necessity to further intensify CKD education among nephrologists (Table 3).

For patients with CKD in G5 (the end-stage of kidney disease), the primary-cause codes provided by nephrologists were mainly the codes related to uraemia, maintenance dialysis or failed transplantation (131, 68.9%), whereas the primary-cause codes provided by general internists were largely related to primary or secondary cause of CKD (107, 60.4%) (Supplementary data, Table S2).

**Nephrology-related medical resources**

The EHRs of patients with CKD in this study were extracted from 42 general hospitals and 257 community healthcare centres. Among the 42 general hospitals, 40 hospitals had general internists, 37 had obstetricians and gynaecologists, 30 had general surgeons and only 3 hospitals had nephrologists (Figure 2).

**Performance of CKD-staging codes**

The performance of each CKD-staging codes in identifying patients with CKD was evaluated in terms of sensitivity, specificity and accuracy. All CKD-staging codes had high specificity (>99.0%) but low sensitivity. The codes of CKD G1 (N18.001, corresponding to N18.1 in the English edition) and G2 (N18.002, corresponding to N18.2 in the English edition) had sensitivities of 0.3 and 1.6%, respectively. Although an increasing trend was observed in codes of advanced stages, the sensitivity was still <10.0% even in the progressed stages of G3 and G4 (Table 4).

**DISCUSSION**

Using EHRs of 976,409 individuals, this study reported the under-diagnosis of CKD in China, illustrated the significant
Table 1. Demographic characteristics of CKD patients and the diagnostic rates using different types of CKD-related ICD codes

| Items                                      | Overall       | G1            | G2            | G3            | G4            | G5            |
|--------------------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Demographic characteristics               |               |               |               |               |               |               |
| In total, n                                | 75 147        | 46 287        | 17 596        | 9217          | 1253          | 794           |
| Age, mean ± SD, years                      | 56.7 ± 17.7   | 49.0 ± 14.0   | 66.2 ± 13.6   | 74.2 ± 12.8   | 73.8 ± 14.6   | 62.3 ± 17.7   |
| Gender, n (%)                              |               |               |               |               |               |               |
| Male                                       | 29 758 (39.6) | 15 275 (33.0) | 8692 (49.4)   | 4719 (51.2)   | 652 (52.0)    | 426 (53.7)    |
| Female                                     | 45 389 (60.4) | 31 012 (67.0) | 8904 (50.6)   | 4498 (48.8)   | 601 (48.0)    | 368 (46.3)    |
| Populations, n (%)                         |               |               |               |               |               |               |
| Outpatient                                 | 47 422 (63.1) | 30 322 (65.5) | 10 560 (60.0) | 5468 (59.3)   | 713 (56.9)    | 359 (45.2)    |
| Inpatient                                  | 27 282 (36.3) | 15 592 (33.7) | 6975 (39.6)   | 3470 (37.7)   | 540 (43.1)    | 435 (54.8)    |
| Albuminuria/proteinuria, n (%)             | 28 867 (38.5) | 17 146 (37.0) | 7136 (40.6)   | 3421 (37.1)   | 719 (57.4)    | 545 (68.6)    |
| Haematuria, n (%)                          | 32 364 (43.1) | 21 851 (47.2) | 7456 (42.4)   | 2324 (25.2)   | 422 (33.7)    | 311 (39.2)    |
| Date of SCr test, n (%)                    |               |               |               |               |               |               |
| Before KDIGO-CKD (2012) guidelines         | 12 678 (16.9) | 7652 (16.5)   | 2920 (16.6)   | 1512 (16.4)   | 312 (24.9)    | 282 (35.8)    |
| After KDIGO-CKD (2012) guidelines          | 62 469 (83.1) | 38 635 (83.5) | 14 676 (83.4) | 7705 (83.6)   | 941 (75.1)    | 512 (64.5)    |
| Diagnostic rates                           |               |               |               |               |               |               |
| Labelled with CKD-staging code, n (%)      | 2140 (2.9)    | 352 (0.8)     | 599 (3.4)     | 767 (8.3)     | 248 (19.8)    | 174 (21.9)    |
| Date of diagnosis                          |               |               |               |               |               |               |
| Before KDIGO-CKD (2012) guidelines         | 15 (0.7)      | 0 (0.0)       | 4 (0.7)       | 4 (0.5)       | 4 (1.6)       | 3 (1.8)       |
| After KDIGO-CKD (2012) guidelines          | 2125 (99.3)   | 352 (100.0)   | 595 (99.3)    | 763 (99.5)    | 244 (98.4)    | 171 (98.3)    |
| Labelled with primary-cause code, n (%)    | 26 857 (35.7) | 14 994 (32.4) | 7502 (42.6)   | 3230 (35.0)   | 655 (52.3)    | 476 (60.0)    |
| Date of diagnosis                          |               |               |               |               |               |               |
| Before KDIGO-CKD (2012) guidelines         | 6300 (23.5)   | 3379 (22.5)   | 1664 (22.2)   | 774 (24.0)    | 237 (36.2)    | 246 (51.7)    |
| After KDIGO-CKD (2012) guidelines          | 20 557 (76.5) | 11 615 (77.5) | 5838 (77.8)   | 2456 (76.0)   | 418 (63.8)    | 230 (48.3)    |
| No CKD-related code, n (%)                 | 46 150 (61.4) | 30 941 (66.9) | 9495 (54.0)   | 5220 (56.6)   | 350 (27.9)    | 144 (18.1)    |
| Date of diagnosis                          |               |               |               |               |               |               |
| Before KDIGO-CKD (2012) guidelines         | 6363 (13.8)   | 4273 (9.3)    | 1252 (13.2)   | 734 (14.1)    | 71 (20.3)     | 33 (22.9)     |
| After KDIGO-CKD (2012) guidelines          | 39 787 (86.2) | 26 668 (57.8) | 8243 (85.9)   | 4486 (85.9)   | 279 (79.7)    | 111 (77.1)    |

aAlbuminuria: urine albumin-to-creatinine ratio ≥30 mg/g or urine albumin excretion ≥30 mg/24h. Proteinuria: urine protein-to-creatinine ratio ≥150 mg/g, or 24-h proteinuria ≥150 mg/24 h or urinalysis protein ≥+1.

bHaematuria: urine red blood cell ≥3 cells/high-power field or urine occult blood ≥+2.

cCKD-staging code: ICD code of CKD in each stage.

dPrimary-cause code: ICD code of primary cause of CKD.

The influence of doctors’ perception on the diagnosis of CKD, and stressed the importance of the CKD education among doctors with different specialties. To our knowledge, it is the first research to report the diagnostic status of CKD and its underlying reasons in China. With the striking development, the allocation of medical resources and people’s health-seeking behaviour, the quality of healthcare in China cannot be solely evaluated by the standard of less developed regions as in the past decades. The present results were from the developed area of China and showed the intermediate state of the development of the healthcare system, which was manifested in the imbalance between relatively sufficient medical resources and yet relatively lagging expertise of primary medical staff. As to CKD, urine and kidney function had been widely detected in China, whereas the abnormal results were frequently overlooked. Taking into consideration the high prevalence of CKD and the frequent interaction between non-nephrologists and CKD patients, intensification of education on CKD among doctors, especially among the non-nephrologists, would be promising to bring about immediate effectiveness on improving the awareness and early management of CKD in developing countries such as China.

Shortage of medical resources and limited healthcare-seeking behaviour are generally considered as the major reasons for low awareness and diagnostic rates of CKD, especially in developing countries [1–3, 12]. The studied region, Yinzhou District, Zhejiang Province, is one of the developed areas in China providing annual physical examination for free to residents aged ≥60 years, primary and middle school students, and farmers [24–26]. Shortage of medical resources was not the main cause of under-diagnosis of CKD in the present region. In addition, laboratory results extracted as the criteria for CKD in this study were those administered by the doctors to the patients who visited the clinics and were willing to receive the tests. Therefore, neither patient’s healthcare-seeking behaviour nor low detection rates were the causes of under-diagnosis of CKD in this study. According to the current results, 12% of patients having persistent proteinuria or haematuria did not undergo assessment of kidney function within 1 year before or after the abnormal urine tests. Although some patients might be unwilling to receive blood tests, it is hard to explain such a high percentage of absence of SCr tests by patient compliance. Whether doctors overlooked the abnormal urine tests, or they were under-perceptive of the linkage between urine problems and kidney injury, these patients were very likely to miss the early intervention for CKD. Stevens et al. [10] and Minutolo et al. [9] reported that low detection rates of SCr were correlated to unsatisfactory CKD diagnosis in the USA and Italy. However, the present results found that 60% of patients who received SCr tests had no diagnosis related to CKD. Doctors who administered the SCr tests failed to recognize the abnormal results, resulting in the high misdiagnosis rate of CKD and low sensitivity of CKD-staging codes. The relatively high utilization rates of primary-cause codes indicated that a number of Chinese doctors had the capacity to diagnose kidney disease, while the low usage of CKD-staging codes further demonstrated the lack of...
perception of CKD as a distinguishing manifestation among the doctors.

According to the current results, a large proportion of patients with CKD were cared for by non-nephrologists. Baldwin [27] reported the positive effects of early nephrology referral on the outcome of CKD and emphasized the better expertise of nephrologists on the management of CKD compared with non-nephrologists. van Dipten et al. [28] reported that CKD was perceived by general practitioners as an abstraction rather than a detailed clinical manifestation. In this study, the majority of CKD patients, even those in advanced stages such as G3 and G4, visited non-nephrologists, whereas the CKD diagnoses were mainly made by nephrologists. Thus, whether patients with CKD received proper management from non-nephrologists was raised as an issue. Compared with massive nephrology referral, especially among patients in early stages of CKD, intensification of CKD education for non-nephrologists was more likely to be time- and cost-efficient. In addition, it should be noted that only 3 of 42 general hospitals involved in this study had nephrologists, while the nephrologists from these 3 hospitals made the majority of CKD diagnoses in the whole region. The heavy burden of nephrologists remains to be solved. Although the deficiency of the nephrology workforce has been shown to be common in low- to middle-income areas [3], this study found that the cultivation of a nephrology-related workforce in a region with a well-built primary healthcare system and a high-quality health information system was still lagging. Policy makers should expend more efforts on improving CKD education and enhancing the nephrology workforce.

This study has advantages. Clinical data from a population of a million from the real world were analysed. Additionally, this study explored the detailed types of CKD diagnosis, the specialty of doctors who interacted with CKD patients, the accessibility of nephrology-related medical resources and the application of KDIGO-CKD clinical guidelines in China. In summary, this study provides detailed and comprehensive clues for policy-makers and doctors to individually improve the strategy of CKD management in China. It also has significance for other developing countries.

This study has several limitations. First, the CKD diagnoses labelled with ICD codes were made within 12 months before or after the SCr tests. The accuracy of CKD-staging codes might be underestimated. Second, the field survey of detailed CKD perception was not completed because of the observational feature. Third, the prognosis of patients in different diagnostic statuses could not be evaluated in this study because of the lack of follow-up information. This is worth investigating in the future.

**CONCLUSION**

The under-diagnosis of CKD is substantial in China and the main cause was under-perception of CKD among doctors with different specialties. Policy-makers should pay more attention to CKD. In addition to the financial investment and population-based screening of CKD, strengthening of CKD education among the doctors might be a quickly cost-efficient solution for improving the diagnostic status and awareness of CKD.

**SUPPLEMENTARY DATA**

Supplementary data are available at cjk online.
Table 3. Specialty of doctors who labelled CKD patients with CKD-staging/primary-cause codes

| Rank | Specialty          | G1 Labelled patients, n (%) | G2 Labelled patients, n (%) | G3 Labelled patients, n (%) | G4 Labelled patients, n (%) | G5 Labelled patients, n (%) |
|------|--------------------|----------------------------|-----------------------------|----------------------------|----------------------------|-----------------------------|
| 1    | Nephrologist       | 134 (52.3)                 | 303 (58.8)                  | 458 (63.5)                 | 142 (64.8)                 | 95 (62.5)                   |
| 2    | General internist  | 82 (32.0)                  | 166 (32.2)                  | 29 (4.0)                   | 5 (2.3)                    | 7 (4.6)                     |
| 3    | Urologist          | 7 (2.7)                    | 10 (1.9)                    | 6 (0.8)                    | 3 (1.4)                    | 2 (1.3)                     |
| 4    | Cardiology         | 6 (2.3)                    | 6 (1.2)                     | 6 (0.8)                    | 3 (1.4)                    | 2 (0.9)                     |
| 5    | Neurologist        | 4 (1.6)                    | 5 (1.0)                     | 4 (0.6)                    | 2 (0.9)                    | –                           |
| Others | Other specialists | 23 (9.0)                  | 25 (4.9)                    | 35 (4.9)                   | 8 (3.7)                    | 10 (6.6)                    |
| Missing | –                   | 96 (23.7)                 | 84 (14.0)                   | 46 (6.0)                   | 29 (11.7)                  | 22 (12.6)                   |

| Rank | Specialty          | G1 Labelled patients, n (%) | G2 Labelled patients, n (%) | G3 Labelled patients, n (%) | G4 Labelled patients, n (%) | G5 Labelled patients, n (%) |
|------|--------------------|----------------------------|-----------------------------|----------------------------|----------------------------|-----------------------------|
| 1    | General internist  | 7331 (50.9)                | 3706 (52.3)                 | 1410 (46.2)                | 287 (46.7)                 | 190 (42.0)                  |
| 2    | Nephrologist       | 2863 (19.9)                | 1393 (19.7)                 | 724 (23.7)                 | 145 (23.6)                 | General internist 38 (25.0) |
| 3    | General surgeon    | 1350 (9.4)                 | 572 (8.1)                   | 186 (6.1)                  | 30 (4.9)                   | Emergency medicine specialist 16 (3.5) |
| 4    | Urologist          | 614 (4.3)                  | 340 (4.8)                   | 113 (3.7)                  | 30 (4.9)                   | Urologist 12 (2.7)          |
| 5    | Endocrinologist    | 505 (3.5)                  | 180 (2.5)                   | 107 (3.5)                  | 26 (4.2)                   | General surgeon 9 (2.0)     |
| Others | Other specialists | 1752 (12.2)                | 894 (12.6)                  | 509 (16.7)                 | 96 (15.6)                  | Other specialists 48 (10.6) |
| Missing | –                   | 579 (3.9)                  | 417 (5.6)                   | 181 (5.6)                  | 41 (6.3)                   | –                           |

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CONFLICT OF INTEREST STATEMENT

L.Z. reports grants from AstraZeneca, independent from this study. The remaining authors have no competing financial interests to declare.

DATA AVAILABILITY STATEMENT

The data underlying this article cannot be shared publicly due to privacy protection.

REFERENCES

1. Couser WG, Remuzzi G, Mendis S et al. The contribution of chronic kidney disease to the global burden of major non-communicable diseases. Kidney Int 2011; 80: 1258–1270
2. Levin A, Tonelli M, Bonventre J et al.; ISN Global Kidney Health Summit participants. Global kidney health 2017 and beyond: a roadmap for closing gaps in care, research, and policy. Lancet 2017; 390: 1888–1917
3. Okpechi IG, Bello AK, Ameh OI et al. Integration of care in management of CKD in resource-limited settings. Semin Nephrol 2017; 37: 260–272
4. Foreman KJ, Marquez N, Dolgert A et al. Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: reference and alternative scenarios for 2016-40 for 195 countries and territories. Lancet 2018; 392: 2052–2090
5. Kidney Disease: Improving Global Outcomes (KDIGO) CKD Work Group. Kidney Disease: Improving Global Outcomes – CKD Evaluation and Management. https://kdigo.org/ guidelines/ckd-evaluation-and-management/ (2012, date last accessed)
6. Komenda P, Rigatto C, Tangri N. Screening strategies for unrecognized CKD. Clin J Am Soc Nephrol 2016; 11: 925–927

Table 4. Identification performance of CKD-staging codes

| ICD-10 code | N18.801 | N18.802 | N18.803 | N18.804 | N18.001 |
|-------------|---------|---------|---------|---------|---------|
| CKD stage   | G1      | G2      | G3      | G4      | G5      |
| in total, n | 46.287  | 17.596  | 9217    | 1253    | 794     |
| Percentage among CKD, % | 61.60 | 23.42 | 12.27 | 1.67 | 1.06 |
| True positive, n² | 120 | 277 | 492 | 106 | 114 |
| True negative, n² | 232 | 322 | 275 | 142 | 60 |
| False positive, n³ | 28.628 | 57.229 | 65.655 | 73.752 | 74.293 |
| False negative, n³ | 46.167 | 17.319 | 87.25 | 1147 | 680 |
| Sensitivity, % | 0.26 | 1.57 | 5.34 | 8.46 | 14.36 |
| 95% CI | 0.21–0.31 | 1.40–1.77 | 4.89–5.82 | 6.98–10.14 | 11.99–16.99 |
| Specificity, % | 99.20 | 99.44 | 99.58 | 99.81 | 99.92 |
| 95% CI | 99.09–99.30 | 99.38–99.50 | 99.53–99.63 | 99.77–99.84 | 99.90–99.94 |
| Accuracy, % | 38.26 | 76.52 | 88.02 | 98.28 | 99.02 |

²Correspondence between CKD and stage codes in the Chinese and in the English edition: N18.801 = N18.1; N18.802 = N18.2; N18.803 = N18.3; N18.804 = N18.4; N18.001 = N18.5.
³True positive was defined if the patients having the levels of eGFR of each stage of CKD were labelled with the correctly correspondent CKD-stage codes.
²True negative was defined if the patients in whom the levels of eGFR were not in one of stages of CKD were not labelled with the correspondent CKD-stage codes.
³False positive was defined if the patients who were labelled with one CKD-stage code showed levels of eGFR of other stages of CKD.
³False negative was defined if the patients having the levels of eGFR of a stage of CKD were not labelled with the correctly correspondent CKD-stage codes.
7. Wouters OJ, O’Donoghue DJ, Ritchie J et al. Early chronic kidney disease: diagnosis, management and models of care. Nat Rev Nephrol 2015; 11: 491–502
8. Gasparini A, Evans M, Coresh J et al. Prevalence and recognition of chronic kidney disease in Stockholm healthcare. Nephrol Dial Transplant 2016; 31: 2086–2094
9. Minutolo R, De Nicola L, Mazzaglia G et al. Detection and awareness of moderate to advanced CKD by primary care practitioners: a cross-sectional study from Italy. Am J Kidney Dis 2008; 52: 444–453
10. Stevens LA, Fares G, Fleming J et al. Low rates of testing and diagnostic codes usage in a commercial clinical laboratory: evidence for lack of physician awareness of chronic kidney disease. J Am Soc Nephrol 2005; 16: 2439–2448
11. Ryan TP, Sloand JA, Winters PC et al. Chronic kidney disease prevalence and rate of diagnosis. Am J Med 2007; 120: 981–986
12. Coresh J, Jafar TH. Disparities in worldwide treatment of kidney failure. Lancet 2015; 385: 1926–1928
13. Jha V, Garcia-Garcia G, Iseki K et al. Chronic kidney disease: global dimension and perspectives. Lancet 2013; 382: 260–272
14. Saunders MR, Kim SD, Patel N et al. Hospitalized patients frequently unaware of their chronic kidney disease. J Hosp Med 2015; 10: 619–622
15. Taylor DM, Fraser SDS, Bradley JA et al.; ATTOM investigators. A systematic review of the prevalence and associations of limited health literacy in CKD. Clin J Am Soc Nephrol 2017; 12: 1070–1084
16. Levey AS, Atkins R, Coresh J et al. Chronic kidney disease as a global public health problem: approaches and initiatives - a position statement from Kidney Disease Improving Global Outcomes. Kidney Int 2007; 72: 247–259
17. Liu ZH. Nephrology in China. Nat Rev Nephrol 2013; 9: 523–528
18. National Kidney Foundation. KDOQI Clinical Practice Guidelines for Chronic Kidney Disease: Evaluation, Classification, and Stratification. http://kdnfoundation.cachefly.net/professionals/KDOQI/guidelines_ckd/index.htm (2002, date last accessed)
19. Zoccali C, Vanholder R, Massy ZA et al.; European Renal and Cardiovascular Medicine (EURECA-m) Working Group of the European Renal Association – European Dialysis Transplantation Association (ERA-EDTA). The systemic nature of CKD. Nat Rev Nephrol 2017; 13: 345–358
20. Boulware LE, Jaar BG, Tarver-Carr ME et al. Screening for proteinuria in US adults: a cost-effectiveness analysis. JAMA 2003; 290: 3101–3114
21. Wang J, Bao B, Shen P et al. Using electronic health record data to establish a chronic kidney disease surveillance system in China: protocol for the China kidney disease network (CK-NET)-Yinzhou study. BMJ Open 2019; 9: e030102
22. Lin H, Tang X, Shen P et al. Using big data to improve cardiovascular care and outcomes in China: a protocol for the Chinese Electronic health Records Research in Yinzhou (CHERRY) study. BMJ Open 2018; 8: e019698
23. Levey AS, Stevens LA, Schmid CH et al.; for the CKD-EPI (Chronic Kidney Disease Epidemiology Collaboration). A new equation to estimate glomerular filtration rate. Ann Intern Med 2009; 150: 604–612
24. Ningbo Municipal People’s Government. Work Report of Ningbo Municipal Government (2012). http://www.ningbo.gov.cn/art/2012/4/20/art_1229181546_51963413.html (2012, date last accessed)
25. Ningbo Municipal People’s Government. Work Report of Ningbo Municipal Government (2011). http://www.ningbo.gov.cn/art/2011/2/28/art_1229181546_51963598.html (2011, date last accessed)
26. Ningbo Municipal People’s Government. Policy Interpretation: Measures for the Implementation of Health Examination Management of Primary and Secondary School Students in Ningbo (2011). http://www.ningbo.gov.cn/art/2011/4/13/art_1229187611_51879434.html (2011, date last accessed)
27. Baldwin MD. The primary care physician/nephrologist partnership in treating chronic kidney disease. Prim Care 2014; 41: 837–856
28. van Dipten C, van Berkel S, de Grauw WJC et al. General practitioners’ perspectives on management of early-stage chronic kidney disease: a focus group study. BMC Fam Pract 2018; 19: 81