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# Prevalence and drug resistance of Escherichia coli among patients with orthopaedic surgical site infections in China: A systematic review and meta-analysis

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ABSTRACT

To summarize current prevalence and drug resistance rate of *Escherichia coli* (*E. coli*) among orthopaedic surgical site infections (SSIs) in China from English and Chinese language sources. Online databases were searched to collect related researches. A *meta*-analysis was performed to analyse prevalence and 95 % confidence interval (CI) of *E. coli* among patients with orthopedic surgical site infections. Meta-regression analysis was used to investigate the difference in the prevalence and antimicrobial resistance of *E. coli* among different subgroups. A total of 52 studies were enrolled into our *meta*-analysis, with a total of 31,285 strains isolated. The overall *E. coli* prevalence was 13.4 % (95 % CI 11.6–15.5). Study design ($R^2 = 8.98$) and sample size ($R^2 = 10.95$) might be potential sources of heterogeneity and there were no significant differences in risk of bias ($R^2 = 0.28$), study time ($R^2 < 0.01$), region ($R^2 = 2.46$) and hospital level ($R^2 = 1.42$). *E. coli* resistance were reported in 43 of the 52 papers. Antimicrobial resistance of *E. coli* to Ampicillin [87.9 % (95 % CI 83.7–91.1)] before 2015 was higher than that after 2015 [80.3 % (95 % CI 75.0–84.7)] ($R^2 = 30.93$, $P = 0.033$). While, resistance rate to Cefepime and Amikacin was significantly higher before 2015 ($R^2 = 17.25$ and 6.54, $P = 0.043$ and 0.048), i.e., 46.4 % (36.3–56.9), 19.9 % (13.8–27.7) and 29.1 % (19.4–41.2), 8.6 % (4.4–16.2) in 2015 and after. It is necessary to carry out long-term monitoring to understand the actual prevalence and antimicrobial resistance of *E. coli* to develop appropriate health care mechanisms.

## 1. Introduction

Surgical site infection (SSI) is the most common complications of surgical patients. It not only brings psychological trauma and prolonged postoperative recovery time, but also increases mortality and medical expenses (Birhanu and Endalamaw, 2020). *Escherichia coli* (*E. coli*) is one of the most prevalent commensal inhabitants of human and the most important conditioned pathogen. Though it rarely causes disease, *E. coli* is responsible for a broad spectrum of diseases including various SSI, such as orthopedic SSI (Li, 2022; Wang, 2022); laparotomy SSI (Huda et al., 2022), laparoscopic hysterectomy (Salmanov et al., 2022) and so on (Nejad et al., 2021). In recent years, drug resistant *E. coli*, even multidrug resistant *E. coli* has gradually increased with the wide use of antibiotics in clinical treatment, which has caused great clinical difficulties and attracted more and more researchers' attention (Hou et al., 2020 Jul; Deka et al., 2020 Dec 21).

According to recent researches, the proportions of orthopaedic surgery patients with SSI are quite different, and *E. coli* is always one of the most significant related pathogens (Xu, 2021; Yu and Zheng, 2021; Chen et al., 2022). In 2014, the National Nosocomial Infection Surveillance System in China found that the total prevalence of SSIs *E. coli* was 20.75 % in all the nosocomial infections, and *E. coli* causes 26.92 % SSIs

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infections in all the 33 pathogens (Nan Ren and Anhua, 2016). And Zheng et al found drug resistant *E. coli* existed in orthopedic trauma, and multidrug resistant *E. coli* was also found in China (Zheng, 2021). Therefore, for an orthopedic surgeon, it is necessary to get a better understand of the epidemiological characteristics and antibiotic resistance of *E. coli* in orthopaedic SSI, which will help to develop more effective prevention and treatment measures.

The purpose of this systematic review and *meta*-analysis was to summarize the current prevalence and drug resistance rate of *E. coli* among orthopaedic SSIs in China from both English and Chinese language sources, and to provide further guidance for the prevention of SSIs.

## 2. Methods

We ran this *meta*-analysis in strict accordance with the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Checklist (https://www.prisma-statement.org/statement.htm).

### 2.1. Search strategy

We used free words combined with subject terms to conducted a carful search in PubMed, Embase, Web of Science, China Biomedical Literature Database (CBM), China National Knowledge Infrastructure (CNKI), Wanfang and Weipu from January 2010 to July 2022. The search terms included surgery, postoperative, surgical wound infection, site infection, *E. coli*, and China. All the retrieved papers were imported to EndNote (version 20), and duplicates were eliminated. All references included in the study were also reviewed.

### 2.2. Inclusion and exclusion criteria

Researches met the following criteria were included in the *meta*-analysis: (1) patients were clinically diagnosed with orthopaedic SSIs; (2) the study subjects were Chinese; and (3) researches were with sufficient data to calculate the prevalence or antimicrobial resistance of *E. coli,* for example the number of *E. coli* strain or resistant *E. coli* strain isolated. The following exclusion criteria were applied: (1) abstracts, reviews, or communication papers; (2) studies with a small number of detected bacterial strains (at least 200 isolated bacterial strains); (3) lack of sufficient information, including incomplete or unavailable research data, for example the number of *E. coli* strain or resistant *E. coli* strain isolated; and (4) research based on data from the National Nosocomial Infection Surveillance System (NNISS). For multiple reports on the same trial, the one with more details and higher quality was selected for analysis.

### 2.3. Data extraction and bias risk assessment

Data were independently extracted by 2 researchers (Luqiao Ou and Gaoming Li) using a unified data table. Author, publication year, study area, research design, hospital level, number of SSIs patients, number of bacterial, *E. coli*, resistant *E. coli* strains isolated, Resistance of drug-

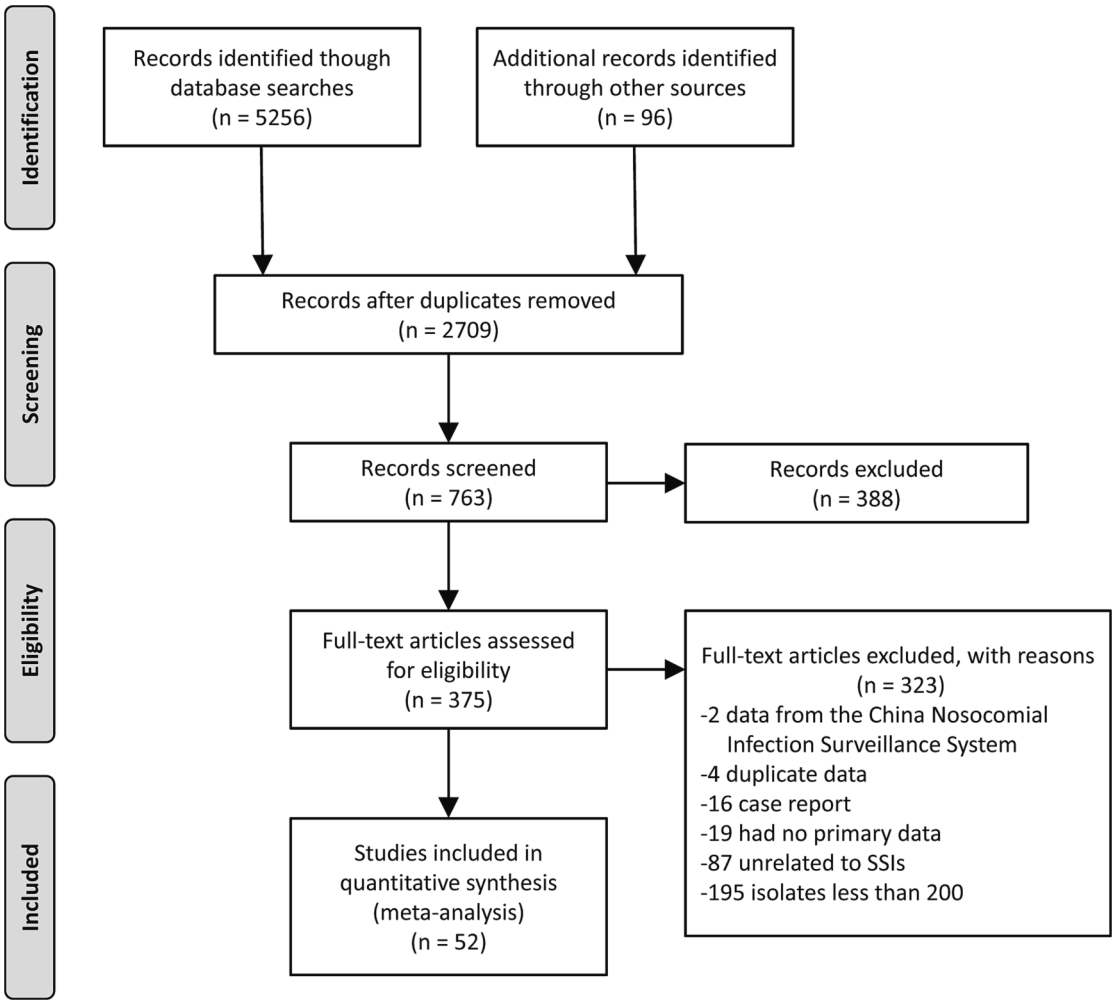


**Fig. 1.** The flowchart showed the selection of studies for *meta*-analysis.

**Table 1**
Characteristics of included studies.

| Study ID | Year | Province | Study type | Hospital level | Number of SSIs patients | Isolates | *Escherichia coli* | Risk of bias |
|---|---|---|---|---|---|---|---|---|
| Feng 2012 | 2009–10 | Zhejiang | Retrospective | Tertiary | 895 | 625 | 140 | High |
| Wang 2012 | 2009–11 | Tianjin | Monitoring | Tertiary | Unclear | 1882 | 99 | Low |
| Wang 2012 | 2009–11 | Jiangxi | Retrospective | Non-tertiary | 269 | 269 | 46 | Low |
| Gao 2013 | 2010–12 | Hebei | Retrospective | Tertiary | 999 | 1056 | 86 | Low |
| Han 2013 | 2010–11 | Shanxi | Retrospective | Tertiary | Unclear | 619 | 62 | High |
| Pan 2013 | 2009–11 | Zhejiang | Retrospective | Non-tertiary | Unclear | 694 | 108 | High |
| Shao 2013 | 2009–11 | Zhejiang | Monitoring | Non-tertiary | 233 | 240 | 51 | Low |
| Cao 2014 | 2011–13 | Shanxi | Retrospective | Non-tertiary | 365 | 210 | 40 | Low |
| Gao 2014 | 2008–12 | Hebei | Monitoring | Tertiary | Unclear | 2456 | 188 | Low |
| Liu 2014 | 2008–12 | Beijing | Monitoring | Tertiary | 587 | 387 | 31 | Low |
| Liu 2014 | 2014 | Hunan | Retrospective | Tertiary | 243 | 243 | 44 | High |
| Xue 2014 | 2012–13 | Henan | Retrospective | Tertiary | 946 | 946 | 227 | Low |
| Zheng 2014 | 2012–13 | Henan | Retrospective | Tertiary | 651 | 407 | 86 | High |
| Su 2015 | 2013–14 | Guangdong | Monitoring | Non-tertiary | 3317 | 603 | 21 | Low |
| Wang 2015 | 2014 | Shandong | Retrospective | Tertiary | 360 | 404 | 116 | High |
| Dong 2016 | 2014–15 | Hebei | Retrospective | Tertiary | 2106 | 2106 | 238 | Low |
| Li 2016 | 2010–14 | Xinjang | Retrospective | Tertiary | 576 | 615 | 84 | Low |
| Wang 2016 | 2011–13 | Beijing | Retrospective | Tertiary | Unclear | 1375 | 105 | Low |
| Chen 2017 | 2014–15 | Jiangsu | Retrospective | Tertiary | 80 | 200 | 26 | Low |
| Guo 2017 | 2014–15 | Henan | Retrospective | Non-tertiary | 285 | 285 | 78 | Low |
| Jin 2017 | 2014–16 | Zhejiang | Retrospective | Non-tertiary | 232 | 296 | 55 | Low |
| Li 2017 | 2012–17 | Zhejiang | Retrospective | Tertiary | 413 | 281 | 34 | Low |
| Liu 2017 | 2012–17 | Zhejiang | Retrospective | Non-tertiary | 70 | 327 | 71 | Low |
| Zeng 2017 | 2016–17 | Guangxi | Retrospective | Non-tertiary | 291 | 341 | 47 | High |
| Sun 2018 | 2016–17 | Zhejiang | Retrospective | Tertiary | 130 | Unclear | 130 | Low |
| Sun 2018 | 2014–16 | Zhejiang | Retrospective | Non-tertiary | 4903 | 2302 | 229 | Low |
| Sun 2018 | 2015–17 | Jiangxi | Retrospective | Tertiary | 216 | 270 | 36 | High |
| Tan 2018 | 2017 | Hubei | Retrospective | Non-tertiary | 280 | 330 | 45 | Low |
| Xie 2018 | 2012–16 | Yunnan | Retrospective | Tertiary | 295 | 345 | 62 | High |
| Yang 2018 | 2015–17 | Tianjin | Retrospective | Tertiary | 2596 | 2471 | 405 | Low |
| Zhang 2018 | 2015–17 | Tianjin | Retrospective | Tertiary | 1269 | 443 | 38 | Low |
| Zhou 2018 | 2017–18 | Zhejiang | Retrospective | Tertiary | 106 | 251 | 112 | High |
| Hu 2019 | 2015–18 | Jiangxi | Retrospective | Non-tertiary | 36 | 206 | 65 | Low |
| Yu 2019 | 2017–18 | Jiangxi | Retrospective | Non-tertiary | 72 | 382 | 20 | Low |
| Zhao 2019 | 2017–18 | Jilin | Retrospective | Tertiary | Unclear | 437 | 35 | High |
| Chai 2020 | 2015–18 | Henan | Retrospective | Non-tertiary | 263 | 342 | 25 | High |
| Gong 2020 | 2015–18 | Sichuan | Retrospective | Tertiary | 1020 | 1020 | 176 | Low |
| Jiang 2020 | 2017–20 | Henan | Retrospective | Non-tertiary | 212 | 236 | 58 | Low |
| Lin 2020 | 2016–19 | Guangdong | Monitoring | Non-tertiary | 409 | 228 | 35 | Low |
| Lu 2020 | 2014–16 | Anhui | Retrospective | Non-tertiary | 200 | 213 | 45 | High |
| Zhang 2020 | 2017–18 | Zhejiang | Retrospective | Tertiary | Unclear | 397 | 21 | High |
| Wang 2021 | 2020 | Liaoning | Monitoring | Tertiary | Unclear | 811 | 56 | Low |
| Wang 2021 | 2015–19 | Henan | Retrospective | Non-tertiary | 562 | 587 | 92 | Low |
| Xu 2021 | 2019 | Gansu | Retrospective | Tertiary | 430 | 252 | 42 | High |
| Yang 2021 | 2017–19 | Henan | Retrospective | Tertiary | 76 | 258 | 62 | Low |
| Ye 2021 | 2018–19 | Fujian | Retrospective | Tertiary | 296 | 296 | 46 | High |
| Yi 2021 | 2019–21 | Hunan | Retrospective | Tertiary | 200 | 200 | 10 | High |
| Yu 2021 | 2015–18 | Guangdong | Retrospective | Tertiary | 516 | 516 | 26 | Low |
| Zheng 2021 | 2020 | Fujian | Retrospective | Tertiary | 890 | 647 | 37 | Low |
| Chen 2022 | 2018–19 | Henan | Retrospective | Tertiary | 265 | 290 | 78 | Low |
| Li 2022 | 2019–21 | Henan | Retrospective | Tertiary | 95 | 463 | 22 | Low |
| Wang 2022 | 2018–21 | Henan | Retrospective | Non-tertiary | 370 | 225 | 40 | Low |

resistant Escherichia coli, and other essential data were collected as main data. Specified diagnostic criteria of original diseases and SSIs, specified criteria of inclusion, case source, case selection method, specified test for pathogenic bacteria, pathogenic test for all included cases and study type were collected to assess the risk of bias. Any disagreement was solved through discussion or consultation with Baochuang Qi.

All the included studies were assessed according to predetermined criteria extracted and modified from a previous case series scale consisting of 9 items. By answering low, high, of unclear to questions, bias can be identified in selected literature. The total score ranges from 0 to 9 points, and the higher the score is, the higher the quality. In this study, R4.1.3 software was used to summarize the risk of bias. A score less than 4 points was defined as high risk, and a score greater than or equal to 4 points was defined as low risk.

### 2.4. Statistical analysis

All statistical analyses were performed using R4.1.3. Statistical tests were all two-tailed. Unless stated, $P < 0.05$ was considered statistically significant. The prevalence of *E. coli* and antimicrobial-resistant *E. coli* isolates among SSI patients in each study was calculated using the following formula:

$$\text{Prevalence of E. coli} = \frac{\text{Number of E. coli isolates}}{\text{Number of all the detected isolates}} \times 100\%$$

$$\text{Prevalence of antimicrobial-resistant E. coli} = \frac{\text{Number of detected E. coli isolates resistant to a given antibiotic}}{\text{Number of E. coli isolates detected}} \times 100\%$$

The prevalence in each study and its 95 % CI were calculated using logit transformation.

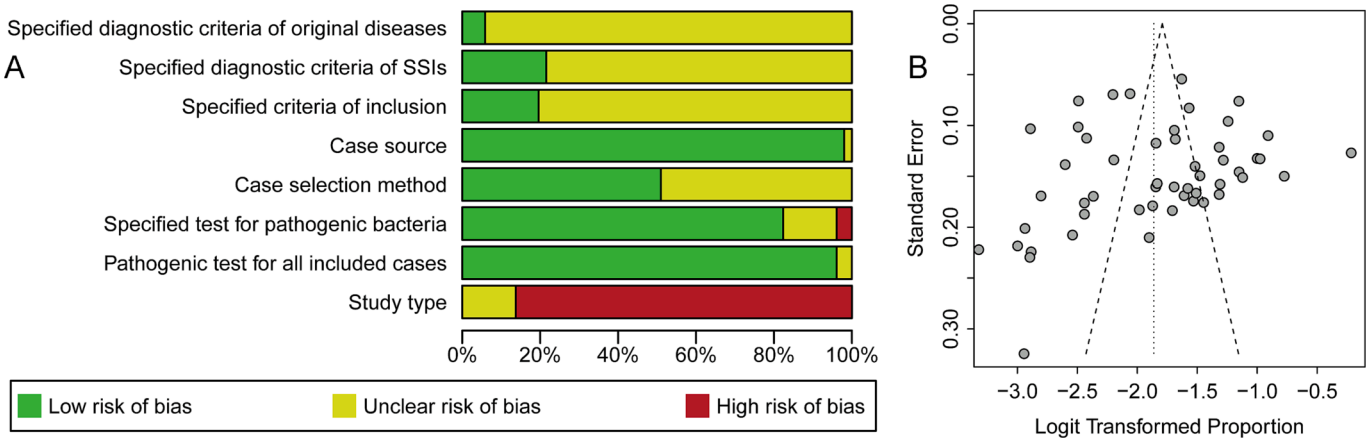


**Fig. 2.** Risk of bias graph and Funnel plots of included studies. A, Risk of bias graph. B, Funnel plots of included studies.

Test of heterogeneity for each outcome was carried out using Cochran's Q test and Higgins I-squared statistic. P value (Q test) $< 0.05$ and/or $I^2 > 50$ % indicated substantial heterogeneity, and a random effect model (Der Simonian and Laird method) was applied accordingly. In contrast, a fixed effect model (inverse variance method) was employed in the presence of mild or low heterogeneity ($P \geq 0.05$ and/or $I^2 < 50$ %). Publication bias was evaluated by Egger's linear regression using the funnel plot.

Subgroup analysis and univariate *meta*-regression were used to evaluate the differences in *E. coli* prevalence and antimicrobial resistance rate. In *meta*-regression analysis, the dependent variable was *E. coli* prevalence or *E. coli* antibiotic resistance data. The independent variables were region (dummy variable: Eastern region), hospital level (dummy variable: Tertiary), risk of bias (dummy variable: High), study design (dummy variable: Retrospective), sample size (dummy variable: <500 isolates), and study time (dummy variable: Before 2015). In *meta*-regression analysis, restricted maximum likelihood method was used to estimate the variance between studies, and the proportion of variance explained by any *meta*-regression model was estimated using $R^2$ statistic.

## 3. Results

We retrieved 5256 articles from online database and 96 from other sources. A total of 2643 duplicates were excluded from the initial articles and 375 relevant full texts were obtained according to our criteria. After examining the publication types, titles, as well as abstracts, 52 studies (Li, 2022; Wang, 2022; Xu, 2021; Yu and Zheng, 2021; Chen et al., 2022; Zheng, 2021; Feng and Mao, 2012; Wang et al., 2012; Wang, 2012; Gao et al., 2013; Han and Gao, 2013; Pan et al., 2013; Shao and He, 2013; Cao, 2014; Gao et al., 2014; Liu and Fang, 2014; Liu et al., 2014; Xue et al., 2014; Zheng, 2014; Su et al., 2015; Wang et al., 2015; Dong and Zhang, 2016; Li et al., 2016; Wang et al., 2016; Chen, 2017; Guo, 2017; Jin et al., 2017; Li et al., 2017; Liu et al., 2017; Zeng, 2017; Sun et al., 2018; Sun et al., 2018; Sun et al., 2018; Tan and Ye, 2018; Xie et al., 2018; Yang et al., 2018; Zhang and Yue, 2018; Zhou et al., 2018; Hu, 2019; Yu and Hu, 2019; Zhao et al., 2019; Chai, 2020; Gong et al., 2020; Jiang et al., 2020; Lin et al., 2020; Lu and Yang, 2020; Zhang et al., 2020; Wang et al., 2021; Wang et al., 2021; Yang and Wang, 2021; Ye et al., 2021; Yi and Huang, 2021) were enrolled into our *meta*-analysis after checking research details Later, all the references in the 52 studies were checked in case of missing eligible records, but no additional record was found. Fig. 1 showed the flow diagram of this study.

The characteristics of 52 included studies are shown in Table 1. Among them, 51 studies reported the proportion of *E. coli* among SSIs, and bacterial strains isolated ranged from 200 to 2471, with a total of 31,285 strains isolated. Another 1 study reported antimicrobial resistance data for *E. coli*. The risk of bias assessment data is shown in Fig. 2A,

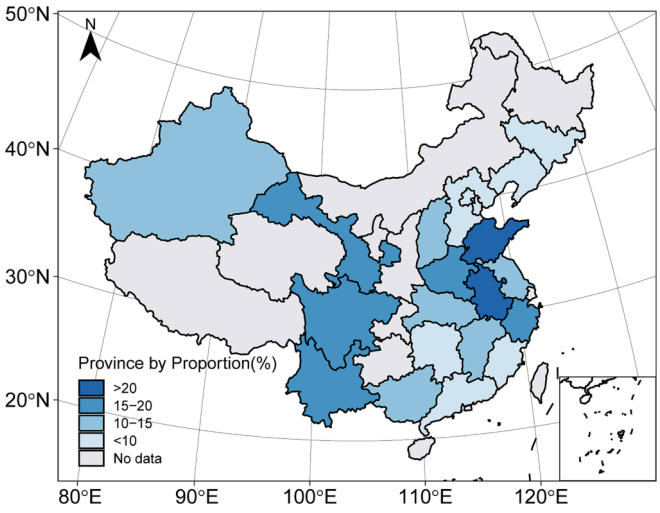


**Fig. 3.** Geographic distribution of *E. coli* prevalence among patients with orthopaedic surgical site infections in China.

and the details are shown in Table S1. There were 34 high-quality studies (≥4), the highest score was 6, and the lowest score was 2 (Table S1). All studies were conducted between 2012 and 2022, and 21 of the 34 provinces in China were represented (Fig. 3). Among them, 25 studies were from the eastern coastal region, 22 from the central region and 5 were from the western region. Most studies were retrospective (45 of 52).

The prevalence of *E. coli* included ranged from 3.5 % (95 % CI 2.3–5.3) to 44.6 % (95 % CI 38.6–50.8) (Fig. 4), indicating significant heterogeneity among these studies. The Higgin's $I^2$ value was 95.8 (Q test $p < 0.001$), and the overall *E. coli* prevalence was 13.4 % (95 % CI 11.6–15.5). The prevalence was 11.6 % (95 % CI 9.3–14.5) in the eastern region, 15.4 % (95 % CI 12.5–18.9) in the central region and 15.9 % (95 % CI 14.2–17.8) in the western region. The prevalence of *E. coli* exceeded 20 % in the 2 provinces: 28.7 % (95 % CI 24.5–33.3) in Shandong and 21.1 % (95 % CI 16.2–27.1) in Anhui. Univariate random effects *meta*-regression analysis indicated that the study design ($R^2 = 8.98$) and sample size ($R^2 = 10.95$) might be potential sources of heterogeneity and there were no significant differences in risk of bias ($R^2 = 0.28$), study time ($R^2 < 0.01$), region ($R^2 = 2.46$) and hospital level ($R^2 = 1.42$) (Table 2). Egger's test indicated no evidence of publication bias regarding the total prevalence of *E. coli* (t = -0.727, p = 0.471; Fig. 2B).

We further analyzed *E. coli* resistance to different antibiotics, and 43 of the 52 papers reported *E. coli* resistance to 56 antibiotics. Among

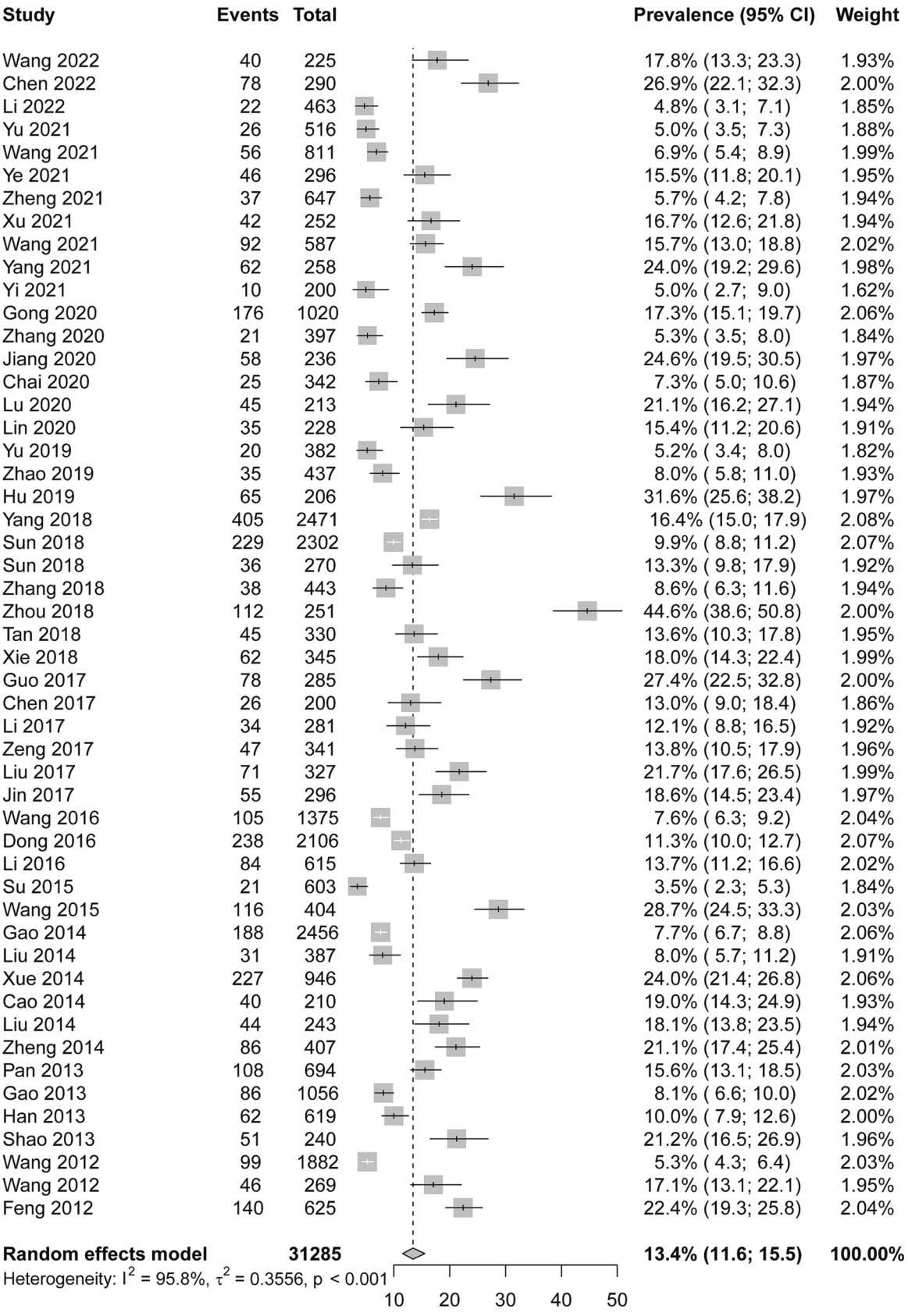


**Fig. 4.** The prevalence of *E. coli* among patients with orthopaedic surgical site infections.

**Table 2**
Prevalence of *E. coli* in different subgroups of patients with orthopedic SSI.

| Group | Prevalence of *Escherichia coli* | | | | | Univariate *meta*-regression | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Studies | Isolates | *Escherichia coli* | Estimate | $I^2$ | β (SE) | OR (95 % CI) | p value | $R^2$ |
| Region | | | | | | | | | |
| Eastern region | 25 | 21,294 | 2374 | 11.6(9.3–14.5) | 96.9 | Ref | Ref | Ref | 2.46 |
| Central region | 21 | 7418 | 1216 | 15.4(12.5–18.9) | 93.0 | 0.322(0.199) | 1.380(0.933–2.040) | 0.106 | |
| Western region | 5 | 2573 | 411 | 15.9(14.2–17.8) | 33.5 | 0.356(0.328) | 1.428(0.751–2.713) | 0.277 | |
| Hospital Level | | | | | | | | | |
| Tertiary | 32 | 22,969 | 2830 | 12.4(10.1–15.0) | 96.6 | Ref | Ref | Ref | 1.42 |
| Non-tertiary | 19 | 8316 | 1171 | 15.5(12.5–19.0) | 93.1 | 0.256(0.196) | 1.292(0.880–1.896) | 0.192 | |
| Risk of bias | | | | | | | | | |
| High | 17 | 6336 | 1037 | 15.1(11.7–19.4) | 94.6 | Ref | Ref | Ref | 0.28 |
| Low | 34 | 24,949 | 2964 | 12.7(10.6–15.1) | 96.0 | −0.203(0.202) | 0.816(0.549–1.214) | 0.316 | |
| Study Design | | | | | | | | | |
| Retrospective | 44 | 24,678 | 3520 | 14.5(12.5–16.7) | 95.0 | Ref | Ref | Ref | 8.98 |
| Non-retrospective[b] | 7 | 6607 | 481 | 8.4(5.7–12.2) | 94.2 | −0.614(0.265) | 0.541(0.322–0.910) | 0.021 | |
| Sample size[c] | | | | | | | | | |
| <500 | 33 | 9954 | 1622 | 15.6(13.0–18.6) | 93.3 | Ref | Ref | Ref | 10.95 |
| ≥500 | 18 | 21,331 | 2379 | 10.3(8.2–12.9) | 96.9 | −0.477(0.188) | 0.621(0.430–0.897) | 0.011 | |
| Year | | | | | | | | | |
| Before 2015 | 26 | 19,386 | 2372 | 14.1(11.6–17.2) | 96.2 | Ref | Ref | Ref | <0.01 |
| 2015 or after | 25 | 11,899 | 1629 | 12.7(10.1–15.9) | 95.4 | −0.123(0.192) | 0.884(0.607–1.288) | 0.521 | |

them, 20 antibiotics were reported in 10 or more studies (Table 3, Fig. 5). We performed a *meta*-analysis of these antibiotics and the antimicrobial resistance rates for *E. coli* were also compared before and after 2015. The results indicated that compared with data before 2015 [80.3 % (95 % CI 75.0–84.7)], antimicrobial resistance of *E. coli* to Ampicillin [87.9 % (95 % CI 83.7–91.1)] was significantly higher in studies after 2015 ($R^2 = 30.93$, $P = 0.033$). While, the rate of resistance to Cefepime and Amikacin was significantly higher before 2015 ($R^2 = 17.25$ and 6.54, $P = 0.043$ and 0.048), i.e., 46.4 % (36.3–56.9), 19.9 % (13.8–27.7) before 2015 and 29.1 % (19.4–41.2), 8.6 % (4.4–16.2) in 2015 and after. In addition, *E. coli* resistance to Cefotaxime, Ceftazidime and Tobramycin showed decreasing trends, and *E. coli* resistance to Ceftriaxone showed increasing trends, but the differences were not statistically significant. Notably, *E. coli* resistance to ampicillin exceeded 80.0 %.

## 4. Discussion

In this study, we conducted a *meta*-analysis of *E. coli* epidemiological characteristics and antimicrobial resistance among orthopaedic SSIs in China. The total prevalence of *E. coli* among SSIs (13.4 %) was significantly lower than the NNISS data (20.75 %) (Nan Ren and Anhua, 2016), and we believe the discrepancy may be caused by the following factors. First, the NNISS data include all nosocomial infections, and the number of bacteria isolated from SSIs was 1638, far less than the 31,285 strains in our study. In addition, the 52 studies included in our study involved more than 62 hospitals distributed in 21 different provinces, including tertiary hospitals and nontertiary hospitals. Second, the studies included in this study were all conducted after 2010, and some (39) were even completed after 2015. However, the NNISS data were collected in 2014. Over time, *E. coli* prevalence among SSI samples may fluctuate, leading to the difference between our results and the NNISS data.

*E. coli* is resistant to a large number of antimicrobial drugs (Kresken et al., 2023), and empirical treatment is dependent on microbiological test results. However, the high resistance of pathogen to antibiotics may increase the possibility of inappropriate empirical treatment, resulting in poor clinical outcomes and increased financial burden. Therefore, in addition to taking appropriate measures in a timely manner and following the antibiotics using guidelines, it is also necessary to design an empirical treatment plan based on antimicrobial susceptibility tests. In addition to intrinsic antimicrobial resistance, *E. coli* can also acquire antimicrobial resistance through other mechanisms and develop into multidrug-resistant or pandrug-resistant bacteria, leading to life-threatening serious infections (Kresken et al., 2023; Nkansa-Gyamfi et al., 2019). Our results showed that the resistance of *E. coli* to Ampicillin was significantly increased, and the resistance to Cefepime and Amikacin was decreased, which provided a reference for clinical prevention and control of *E. coli* infection among SSIs.

In this study, the *E. coli* resistance rate to the third generation cephalosporins, ceftriaxone (65.6 %, 2015 or after) and cefotaxime (46.8 %, 2015 or after), was slightly different from that reported by the Chinese Antimicrobial Resistance Surveillance System (CARSS) in 2020 (51.6 %) (https://www.carss.cn/Report/Details?aId = 808). The *E. coli* resistance rate to carbapenems, including imipenem (2.5 %, 2015 or after) and meropenem (2.5 %, 2015 or after) is comparable to the CARSS data in 2020 (1.6 %). And when comes to quinolone drugs, including levofloxacin (48.4 %, 2015 or after) and ciprofloxacin (54.0 %, 2015 or after), the situation is also similar (the CARSS data 50.7 %).

This study has the following limitations. First, the heterogeneity among the included studies was considerable, subgroup analysis and *meta*-regression analysis could not fully explain the heterogeneity. Second, studies with small sample size are prone to producing accidental results, and neglect of these studies may result in a lack of some potential important data. Third, the majority of regions included were the central and eastern coastal areas of China, and SSI monitor was more popularized. Therefore, the estimated *E. coli* prevalence may not reflect the overall situation in China. Fourth, SSIs sample collection, strains identification including *E. coli* detection, antimicrobial resistance evaluation methods may be not strictly consistent in collected researches, for example the strains identification and antimicrobial resistance evaluation were completed by different equipment or even by artificial approach, which would lead to a different frequency. Finally, we only described the antimicrobial resistance status of *E. coli* in SSIs without covering related mechanism, further research might as well pay attention to the expression of drug resistance genes, which would also be reference for medication strategies and prognostic indicator selection (Halaji et al., 2022; Halaji et al., 2020; Halaji et al., 2020).

In summary, *E. coli* prevalence and antimicrobial resistance vary with region and time, which need to be monitored at all times. Compared with the NNISS data, *E. coli* prevalence among SSIs in this study was lower. Therefore, it is necessary to carry out long-term monitoring to understand the actual prevalence and antimicrobial resistance of *E. coli* to develop appropriate health care mechanisms. According to findings of the current research, the antibiotic therapy concerning orthopaedic SSIs may require minor adjustments in China. We therefore recommend initiating appropriate infection prevention measures, strengthening existed antimicrobial stewardship programmes, and conducting regular antimicrobial surveillance to prevent antimicrobial-resistant *E. coli* infection in hospitals.

**Table 3**
Combined prevalence of drug-resistant E. coli at different times.

| | Year | Prevalence of resistant *Escherichia coli* | | | | | Univariate *meta*-regression | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Studies | *Escherichia coli* | Resistant *Escherichia coli* | Estimate | $I^2$ | β (SE) | OR (95 % CI) | p value | $R^2$ |
| Ampicillin | Before 2015 | 9 | 538 | 439 | 80.3 (75.0–84.7) | 37.2 | Ref | Ref | Ref | 30.93 |
| | 2015 or after | 16 | 1035 | 911 | 87.9 (83.7–91.1) | 61.1 | 0.506 (0.238) | 1.659 (1.041–2.644) | 0.033 | |
| Ampicillin-sulbactam | Before 2015 | 4 | 309 | 165 | 52.5 (26.1–77.7) | 95.0 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 6 | 333 | 161 | 38.5 (25.3–53.7) | 81.7 | −0.594 (0.572) | 0.552 (0.180–1.694) | 0.299 | |
| Aztreonam | Before 2015 | 11 | 767 | 316 | 40.8 (34.1–47.9) | 69.7 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 11 | 644 | 299 | 46.3 (35.9–57.1) | 79.6 | 0.216 (0.293) | 1.242 (0.699–2.205) | 0.460 | |
| Cefazolin | Before 2015 | 9 | 915 | 607 | 63.2 (46.7–77.1) | 94.2 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 11 | 723 | 508 | 71.1 (59.9–80.3) | 87.3 | 0.380 (0.431) | 1.462 (0.629–3.400) | 0.378 | |
| Cefepime | Before 2015 | 13 | 1216 | 581 | 46.4 (36.3–56.9) | 91.0 | Ref | Ref | Ref | 17.25 |
| | 2015 or after | 15 | 771 | 236 | 29.1 (19.4–41.2) | 86.4 | −0.748 (0.371) | 0.473 (0.229–0.978) | 0.043 | |
| Cefoperazone-sulbactam | Before 2015 | 6 | 634 | 103 | 17.6 (9.1–31.4) | 90.1 | Ref | Ref | Ref | |
| | 2015 or after | 10 | 624 | 64 | 7.5(3.7–14.7) | 79.4 | −0.944 (0.588) | 0.389 (0.123–1.232) | 0.108 | |
| Cefotaxime | Before 2015 | 7 | 669 | 373 | 56.6 (48.5–64.3) | 73.3 | Ref | Ref | Ref | 11.82 |
| | 2015 or after | 7 | 280 | 121 | 46.8 (34.9–59.1) | 72.9 | −0.414 (0.285) | 0.661 (0.378–1.155) | 0.146 | |
| Ceftazidime | Before 2015 | 16 | 1322 | 541 | 43.6 (34.6–53.0) | 89.7 | Ref | Ref | Ref | 2.85 |
| | 2015 or after | 17 | 959 | 339 | 32.8 (24.4–42.5) | 86.5 | −0.457 (0.295) | 0.633 (0.355–1.128) | 0.121 | |
| Ceftriaxone | Before 2015 | 8 | 412 | 216 | 51.8 (39.5–63.9) | 82.8 | Ref | Ref | Ref | 7.79 |
| | 2015 or after | 15 | 973 | 642 | 65.6 (55.5–74.4) | 87.9 | 0.574 (0.353) | 1.776 (0.889–3.544) | 0.104 | |
| Cefuroxime | Before 2015 | 5 | 670 | 433 | 66.7 (52.2–78.7) | 91.8 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 7 | 420 | 242 | 60.5 (48.7–71.2) | 80.5 | −0.265 (0.358) | 0.767 (0.381–1.548) | 0.460 | |
| Imipenem | Before 2015 | 18 | 1442 | 40 | 3.3(2.1–5.3) | 43.9 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 21 | 1178 | 89 | 2.5(0.7–8.0) | 90.4 | 0.253 (0.561) | 1.288 (0.428–3.869) | 0.653 | |
| Meropenem | Before 2015 | 12 | 1125 | 43 | 2.2(0.8–6.1) | 85.3 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 11 | 579 | 18 | 2.5(0.5–11.2) | 84.7 | 0.285 (0.824) | 1.330 (0.265–6.692) | 0.729 | |
| Piperacillin | Before 2015 | 14 | 1394 | 886 | 64.3 (51.2–75.5) | 94.1 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 10 | 440 | 247 | 62.0 (51.7–71.3) | 69.1 | −0.134 (0.423) | 0.875 (0.382–2.006) | 0.752 | |
| Piperacillin-tazobactam | Before 2015 | 9 | 939 | 97 | 8.3(4.6–14.4) | 83.8 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 10 | 481 | 18 | 5.6(2.9–10.6) | 41.1 | −0.504 (0.493) | 0.604 (0.230–1.589) | 0.307 | |
| Amikacin | Before 2015 | 15 | 1319 | 278 | 19.9 (13.8–27.7) | 87.9 | Ref | Ref | Ref | 6.54 |
| | 2015 or after | 15 | 853 | 85 | 8.6(4.4–16.2) | 85.2 | −0.869 (0.439) | 0.419 (0.177–0.992) | 0.048 | |
| Gentamycin | Before 2015 | 17 | 1467 | 734 | 48.9 (42.8–55.0) | 79.3 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 15 | 814 | 376 | 45.1 (39.6–50.8) | 54.9 | −0.165 (0.187) | 0.848 (0.588–1.223) | 0.378 | |
| Tobramycin | Before 2015 | 5 | 396 | 164 | 44.6 (32.4–57.6) | 83.0 | Ref | Ref | Ref | 15.35 |
| | 2015 or after | 10 | 747 | 203 | 26.2 (17.4–37.4) | 87.3 | −0.824 (0.429) | 0.439 (0.189–1.017) | 0.055 | |
| Ciprofloxacin | Before 2015 | 12 | 1210 | 711 | 58.7 (49.8–67.0) | 87.8 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 15 | 866 | 458 | 54.0 (46.6–61.2) | 74.9 | −0.192 (0.254) | 0.825 (0.501–1.359) | 0.450 | |

(*continued on next page*)

**Table 3** (*continued*)

| | Year | Prevalence of resistant *Escherichia coli* | | | | | Univariate *meta*-regression | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Studies | *Escherichia coli* | Resistant *Escherichia coli* | Estimate | $I^2$ | β (SE) | OR (95 % CI) | p value | $R^2$ |
| Levofloxacin | Before 2015 | 11 | 868 | 445 | 48.3 (40.8–55.8) | 77.2 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 16 | 860 | 411 | 48.4 (37.7–59.1) | 86.8 | 0.027 (0.344) | 1.028 (0.524–2.017) | 0.937 | |
| Bactrim | Before 2015 | 7 | 507 | 322 | 63.9 (54.1–72.7) | 73.8 | Ref | Ref | Ref | <0.01 |
| | 2015 or after | 8 | 435 | 272 | 63.3 (56.2–69.8) | 45.3 | −0.008 (0.270) | 0.992 (0.585–1.684) | 0.977 | |

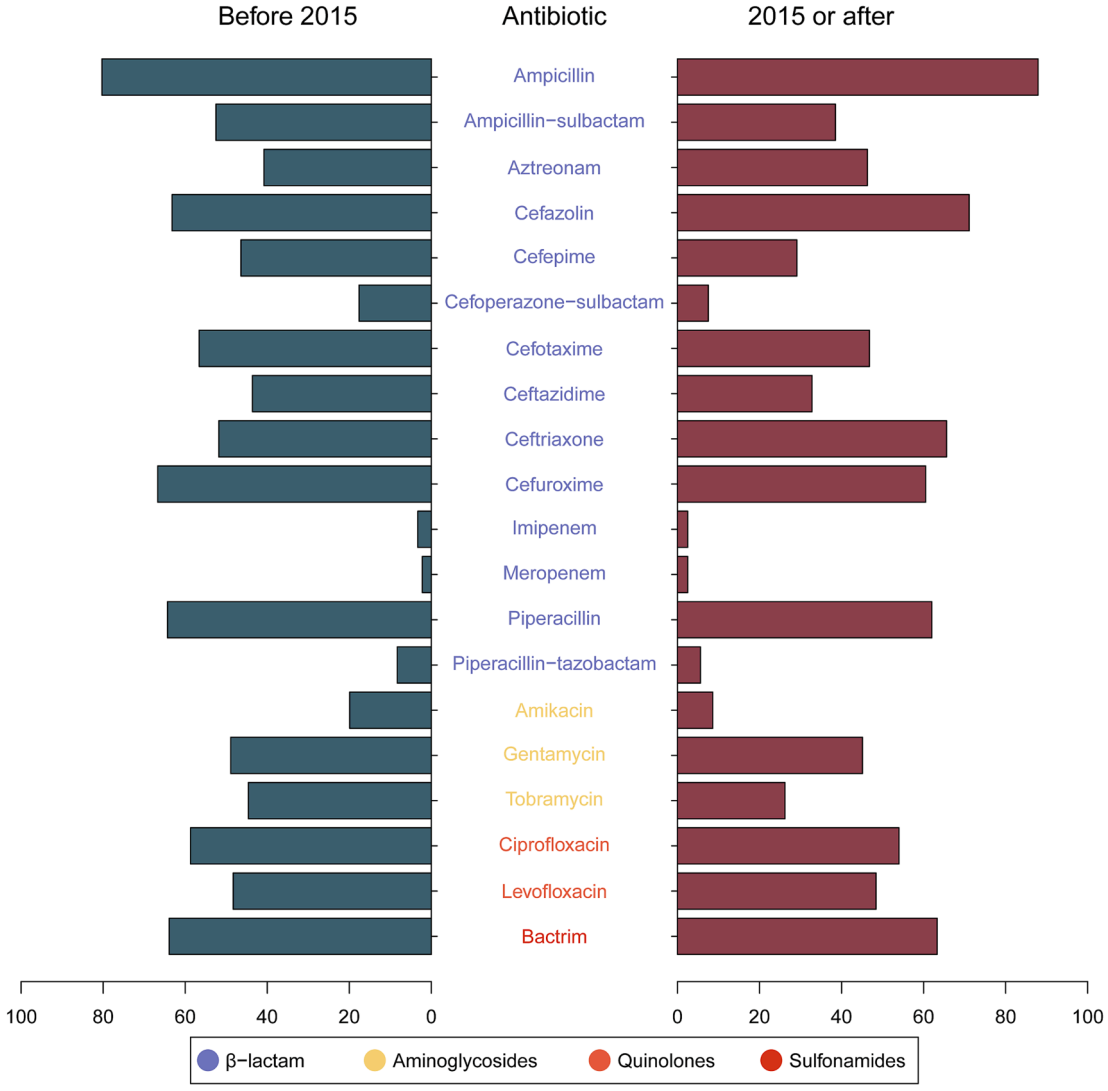


**Fig. 5.** Antibiotic resistance rates for *E. coli* for different subgroups of years.

## CRediT authorship contribution statement

**Luqiao Pu:** Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization. **Gaoming Li:** Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization. **Baochuang Qi:** Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization. **Chuan Li:** Writing – original draft. **Pengfei Bu:** Writing – original draft. **Yapin Li:** Writing – original draft. **Ze Xu:** Writing – original draft. **Yan Bai:** Writing – review & editing. **Dehong Yin:** Writing – review & editing. **Jian Wang:** Conceptualization, Supervision, Project administration. **Yongqing Xu:** Conceptualization, Funding acquisition, Supervision, Project administration.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

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