Metrics for quantifying antibiotic use in the hospital setting: results from a systematic review and international multidisciplinary consensus procedure

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Background: Quantifying antibiotic use is an essential element of antibiotic stewardship since it allows comparison between different settings and time windows, and measurement of the impact of interventions. However, quantity metrics (QMs) and methods have not been standardized.

Objectives: To propose a set of QMs for antibiotic use in inpatients (IQMs) that are accepted globally by professionals in a range of disciplines. The study was conducted within the Driving Reinvestment in Research and Development and Responsible Antibiotic Use (DRIVE-AB) project.

Methods: A systematic literature review using MEDLINE identified articles on measuring inpatient antibiotic use, published up to 29 January 2015. A consensually selected list of national and international web sites was screened for additional IQMs. IQMs were classified according to the type of numerator used and presented to a multidisciplinary panel of stakeholders. A RAND-modified Delphi consensus procedure, which consisted of two online questionnaires and a face-to-face meeting, was performed.

Results: The systematic literature review and web site search identified 168 eligible articles from which an initial list of 20 IQMs, composed of 20 different numerators and associated denominators was developed. The consensus procedure resulted in a final set of 12 IQMs. Among this final set, DDDs per 100(0) patient-days and days of therapy per patient-days were most frequently found in the review. The panel recommended that antibiotic use should be expressed in at least two metrics simultaneously.

Conclusions: Our consensus procedure identified a set of IQMs that we propose as an evidence-based global standard.

Introduction

Introduction of antibiotic treatment, together with hygiene measures, was probably one of the main causes for the notable reduction in morbidity and mortality rates caused by bacterial infections in the last century.1 However, infections with bacteria resistant to many commonly used antimicrobials are one of the major treatment challenges nowadays.2 The development of new antibiotics and the responsible use of existing ones represent valuable options to combat the spread and emergence of antimicrobial resistance.
Since the development of new antibiotics is a difficult endeavour due to scientific complexity, and financial, time and safety issues, responsible use of existing antibiotics remains crucial to preserve their effectiveness.3 Measuring the quantity of antibiotic use is one of the key strategies in antimicrobial stewardship programmes since measurement of antibiotic use is the first step that leads to control and eventually to an improvement of use.6 Quantity metrics may reflect the volume or costs of antibiotic use and proper comparison of antibiotic consumption is enabled only by standardization of its quantification.6 Zanichelli et al.5 showed a large variation in quantitative metrics for antibiotic use across similar settings and providers and for specific medical conditions and populations, both in high- and low- to middle-income countries. Reducing antimicrobial resistance through responsible antibiotic use and identifying how to incentivize the discovery and development of novel antibiotics through new economic models are the most important goals of the Driving Reinvestment in Research and Development and Responsible Antibiotic Use (DRIVE-AB) project, funded by the Innovative Medicines Initiative.6,7

This study, which is part of the DRIVE-AB project, aimed to develop a set of evidence-based and consensually validated quantity metrics for antibiotic use for the inpatient setting. Additionally, inpatient quality indicators are presented by Monnier et al.8

Materials and methods

Systematic review of the literature

A systematic literature review, followed by a RAND-modified Delphi consensus procedure, was performed according to previously described methods.9–11 This review is reported according to the PRISMA statement.12

The MEDLINE (via the PubMed interface) electronic database from inception until 29 January 2015 was searched. The search strategy was built using the combination of four main search term concepts: (i) antibiotics; (ii) quantity/utilization; (iii) measurement unit; and (iv) inpatient (a detailed list of search terms is provided in Table S1, available as Supplementary data at JAC Online). In addition, the reference lists of papers concerning (methodological) issues in quantifying antibiotic use/prescribing were hand-searched to identify any additional relevant studies.

Inclusion and exclusion criteria

Articles were included if they were written in English, concerned systemic (i.e. not topical, vaginal, or inhaled) antibiotic use in humans and reported quantity metrics for antibiotic use/prescribing in the hospital setting, as papers on antiviral, antifungal and antiparasitic drugs were excluded, as well as articles describing antibiotic use in tuberculosis and in pathologies included in the Orphanet list of rare diseases.13

Papers were selected for full-text screening if they fulfilled any of the following criteria:

- reviews which described metrics used in literature; OR
- papers comparing two or more different quantity metrics for antibiotic use/prescribing; OR
- papers which used the quantity metric (one or more) to assess correlation between antibiotic use and selection or propagation of antimicrobial resistance; OR
- papers which developed a new (unknown) quantity metric for antibiotic use/prescribing; OR
- papers concerning (methodological) issues in quantifying antibiotic use/prescribing.

Papers for which the full text could not be retrieved from any of the libraries of the participating centres (five different catalogues) were also excluded.

Screening process, data collection and analysis

Special systematic review software (DistillerSR, Evidence Partners, Ottawa, Ontario, Canada) was used for literature screening based on defined inclusion and exclusion criteria. Two reviewers (M. S. B., R. M.) independently screened the titles and abstracts of the records retrieved by the initial search. Discrepancies between the reviewers were resolved through a discussion with a third reviewer (V. V.-P.). Three reviewers (M. S. B., R. M., V. V.-P.) independently extracted relevant data from included articles. A random selection of 10 papers was used as a pilot test to clarify any ambiguities in the process of data extraction. From the eligible studies, the following data were retrieved: study objective; study design (cross-sectional, prospective, retrospective, literature review); the type of quantitative metric (e.g. volume, cost); and the definition of metric by numerator/denominator.

All extracted inpatient quantity metrics (IQMs) from the included studies were grouped into categories based on the numerator. These IQMs were then presented to the stakeholders in the consensus procedure.

Web site search

The web sites of national and international organizations were also searched for data reporting antibiotic IQMs published until 29 January 2015. Two reviewers (M. S. B. and R. M.) screened a selection of relevant web sites. These web sites were selected based on a discussion with all study authors. The list of searched web sites is presented in Table S2. Data were extracted and all extracted IQMs from the included web sites were grouped into categories based on the numerator and presented to the stakeholders in the consensus procedure.

RAND-modified Delphi procedure

The RAND-modified Delphi procedure consisted of a two-round online survey addressed to a multidisciplinary expert panel of stakeholders with a face-to-face meeting held between the two surveys. International stakeholders were invited by e-mail to participate. The selection process of the stakeholders is described elsewhere.15 Fifty-two stakeholders amongst four different groups, aiming at representing all parties involved with antibiotic use/prescribing, were invited: medical community (n = 15); public health and patients (n = 12); antibiotic research and development (R&D) (n = 14); and payers, policy makers, governments and regulators (n = 11). These are detailed in Table S3. The IQMs extracted from the included studies and web sites were classified according to the category of the numerator and similar IQMs were grouped together (e.g. numerator: Treatment courses categorized together with Treatment period). The list of IQMs was converted into an internet-based questionnaire (Figure S1) using SurveyMonkey® (Palo Alto, CA, USA). Stakeholders assessed the relevance of the extracted IQMs in the first-round internet-based questionnaire using a nine-point Likert scale ranging from 1, “Clearly not relevant”; to 9, “Clearly relevant”; plus a “Cannot assess” option, and there was a comments box for each IQM. IQMs were selected if the median score was ≥7 with agreement, held for discussion if the median score was ≥7 with disagreement, and rejected if the median score was <7. Agreement was defined as >70% of the scores being in the top tertile (score 7–9). Additionally, stakeholders were asked to select relevant denominators (one or more) for each of the proposed IQM numerators. The stakeholders also had an option to propose new IQMs that had not been presented in the first online survey.

After the first online survey, a face-to-face consensus meeting with stakeholders was held to discuss disagreements and to evaluate newly suggested metrics. During the meeting the stakeholders could accept, rephrase or reject presented IQMs.
A detailed overview of the first survey and face-to-face meeting was submitted to the multidisciplinary stakeholder panel in a second internet-based survey (data not shown). Stakeholders could accept or reject the updated set of IQMs and comment on any relevant issues. Finally, IQMs were accepted if >70% of the respondents agreed with their selection.

**Results**

**Systematic review of the literature and web sites**

The flow chart of the review process is shown in Figure 1. The initial search of the MEDLINE database identified 1152 articles. An additional 41 articles were identified through cross-referencing (n = 13) and searching of web sites (n = 28). By screening the abstracts, 968 articles and duplicates were excluded. An additional 57 articles were excluded for the following reasons: 29 did not have full text available and 28 did not meet the inclusion criteria. The complete search resulted in 168 articles (140 from MEDLINE and 28 from web sites). Table S4 shows the articles and the following characteristics: author, year of publication, country, socioeconomic setting, study design, specific populations and objectives of the studies included in the review. In addition, summary descriptions of included studies are presented in Table S5. Based on the numerator, 20 different classes of IQMs were generated (74 numerator/denominator combinations). The definitions of all included IQMs are listed in Table 1. The consensus process with final IQMs is described in Table 2.

**Results of the first online-based stakeholder survey**

Twenty-three of the 52 stakeholders initially invited (44%) completed the survey between August and September 2015. Out of the 20 IQMs presented for assessment through the first online-based survey questionnaire, ‘Days of therapy (DOT)’, with all denominators, was selected for the second online survey;
Results of the second online-based stakeholder survey

The second round was completed between December 2015 and February 2016. Overall response rate was 88% (22 out of 25 invited stakeholders completed the survey). The result of the consensus procedure as a final set of 12 IQMs of antibiotic use is shown in Table 3.

Discussion

This study identified 12 IQMs as appropriate for quantifying antibiotic use by a Delphi procedure including a multidisciplinary panel of international stakeholders (Figure 2). The 12 IQMs represent only one-sixth of the comprehensive list of 74 IQMs generated through a systematic review of the literature and relevant web sites. In addition, new IQMs were added by the panel. The consensus procedure identified the limitations of individual IQMs, and stakeholders specifically proposed a preference that antibiotic use be quantified in at least two different metrics simultaneously. Other authors have stated that, although each IQM individually measures and describes different aspects of antibiotic prescribing,
Table 2. The consensus process of selecting the inpatient quantity metrics for antibiotic use

| Proposed numerator/denominators | Conclusion after the first survey | Conclusion after the consensus meeting | Final conclusion after the second survey |
|--------------------------------|----------------------------------|---------------------------------------|------------------------------------|
| **I. Defined daily doses (DDDs)**<sup>(c)</sup> | Labelled for discussion | Selected | Selected |
| No denominator | | 100(0) PDs/BDs/OBDs<sup>(c)</sup> | IQM 1 |
| Admissions | | | |
| 100 BDs per CMI<sup>(d)</sup> | | 100 BDs per CMI (35%) | IQM 3 |
| 1000 inhabitants per day | | | |
| Discharges | | | |
| Age-adjusted comorbidity score, 100 PDs/age adjusted comorbidity score | | | |
| FCEs<sup>e</sup> | | | |
| Number of treatment days | | | |
| Patients | | | |
| 100 BDs/E | | | |
| 100 admissions per CMI | | | |
| **II. Hospital-adjusted DDDs (haDDDs)** | Rejected | – | – |
| No denominator | | 100 PDs | |
| 100 discharges | | | |
| **III. Prescribed daily dose (PDDs)** | Labelled for discussion | Selected | IQM 4 |
| No denominator | | 100 PDs (70%) | |
| Admissions | | | |
| DDDs | | | |
| RDDs | | | |
| **V. Recommended daily doses (RDDs)** | Rejected | – | – |
| No denominator | | 100 PDs | |
| PDs | | | |
| **V. Doses/unit (mg/kg/day or g/patient/day or g or mg)** | Rejected | – | – |
| No denominator | | | |
| Days of therapy | | | |
| **VI. Packages** | Rejected | – | – |
| No denominator | | | |
| **VII. Prescriptions** | Rejected | – | – |
| No denominator | | | |
| Admissions | | | |
| **VIII. Average number of drugs (antibiotics) per prescription** | Rejected | – | – |
| No denominator | | | |
| **IX. Days of therapy (DOT) (synonym: antibiotic days or antimicrobial days)** | Selected | Selected | IQM 5 |
| No denominator | | PDs (52%) | |
| Patients | | Patients (30%) | IQM 6 |
| Admissions | | Admissions (30%) | IQM 7 |
| Discharges | | | |
| Length of therapy (LOT) | | | |
| Expected days of therapy (DOT) | | | |
| **X. Antibiotic days or antimicrobial days** | Rejected | – | – |
| No denominator | | | |
| Admissions | | | |
| 1000 FCEs | | | |
| **XI. Agent days** | Rejected | – | – |
| No denominator | | | |
| Admissions | | | |
| 1000 FCEs | | | |

Continued
| Proposed numerator/denominators | Conclusion after the first survey | Conclusion after the consensus meeting\(^a\) | Final conclusion after the second survey |
|--------------------------------|----------------------------------|---------------------------------------------|-----------------------------------------|
| **XII. Length of therapy (LOT)** |                                  |                                             |                                         |
| No denominator                 | Labelled for discussion          | Selected PDs (44%)                          | Selected                                |
| PDs                            |                                  |                                             |                                         |
| Admissions                     |                                  | Admissions (39%)                           | IQM 8                                   |
| Patients                       |                                  | Patients (30%)                             | IQM 9                                   |
| Discharges                     |                                  |                                             |                                         |
| 1000 FCEs                      |                                  |                                             |                                         |
| **XIII. Treatment courses (synonym: treatment period)** | Reject | Reject | Reject |
| No denominator                 |                                  |                                             |                                         |
| Admissions                     | Reject                           | Reject                                      | Reject                                  |
| PDs                            |                                  |                                             |                                         |
| 1000 FCEs                      |                                  |                                             |                                         |
| Total number of treatment courses |                                 |                                             |                                         |
| **XIV. Percentage of classes of antimicrobials that accounted for more than a certain percentage (10% or 50%) of treatment courses** | Reject | Reject | Reject |
| No denominator                 | Reject                           | Reject                                      | Reject                                  |
| **XV. Number or percentage of different antibiotics used/prescribed** | Reject | Reject | Reject |
| No denominator                 | Reject                           | Reject                                      | Reject                                  |
| Patient                        |                                  |                                             |                                         |
| Days of treatment              |                                  |                                             |                                         |
| 1000 resident care days        |                                  |                                             |                                         |
| Hospital                       |                                  |                                             |                                         |
| **XVI. Length of stay (LOS) or antibiotic-related length of stay (ALOS)** | Reject | Reject | Reject |
| No denominator                 | Reject                           | Reject                                      | Reject                                  |
| PDs                            |                                  |                                             |                                         |
| **XVII. Patients**             |                                  |                                             |                                         |
| All patients                   | Labelled for discussion          | Selected All patients (26%)                 | Selected                                |
| Admissions                     |                                  | All patients (26%)                         | IQM 10                                  |
| **XVIII. Drug utilization index (DU) DU 75%, DU 90%, DU 100%** | Reject | Reject | Reject |
| No denominator                 | Reject                           | Reject                                      | Reject                                  |
| **XIX. Antibiotic costs**      |                                  |                                             |                                         |
| No denominator                 | Reject                           | Reject                                      | Reject                                  |
| PDs                            |                                  |                                             |                                         |
| **XX. Drug cost index 90% (DC 90%)** | Reject | Reject | Reject |
| No denominator                 | Reject                           | Reject                                      | Reject                                  |
| **XXI. Antibiotic use should be preferably expressed in at least two metrics simultaneously** | Reject | Newly suggested | Selected: IQM 12 |

\(^a\)Top two/three denominators ranked by the stakeholders.

\(^b\)Bold text shows inpatient quantity metrics that were selected as a result of the consensus procedure.

\(^c\)100 or 1000 patient-days (PDs)/bed-days (BDs)/occupied bed-days (OBDs).

\(^d\)CMI, case mix index. This is a relative value assigned to a diagnosis-related group of patients in a medical care environment.

\(^e\)FCE, finished consultant episode. This is an NHS term for a consultant episode that has ended due to discharge, transfer or death.
the actual antibiotic use can be more precisely evaluated in combination with at least one additional IQM.16,17 The three IQMs with DDDs as a numerator selected in the consensus procedure represent widely used metrics that can relatively easily be obtained and calculated and can thus be used to measure the use of different antibiotics, across different centres and countries.16 However, although the Infectious Diseases Society of America released a guideline in which DDDs is recommended for benchmarking purposes, there are still too many IQMs on antibiotic use present in the published literature that preclude a valid comparison of data within and between institutions.5,17 On the other hand, using only DDDs for comparison purposes does not always offer a clear, realistic picture of antibiotic use in practice.18 DDDs as a metric is relevant only for adult populations.19 Some of the factors that may influence variations in antibiotic use measured in DDDs are reductions in administered daily dose (e.g. renal impairment, weight-based dosing in children), different dosing recommendations in different countries and route of administration (oral, parental).20,21 Hence, as pointed out by others, in order to enable more informative benchmarking, other IQMs, including PDDs, DOT, LOT and exposed patients, all as numerators, may yield a more valid description of antibiotic exposure than DDDs alone.22–24 Polk et al.25 and Dalton et al.26 analysed similarities and differences between DDDs and DOT. For example, when the administered dosage was less than the DDDs, such as for ceftriaxone in the study by MacDougall and Polk,26 estimates of use based on DDDs/1000 patient-days (PDs) were significantly lower than those based on DOT/1000 PDs. Addition of another unit of measure, such as DOT, might also be helpful to meaningfully interpret data on the impact of antibiotic use, since the effects on the microbiota might depend more on total duration of treatment than on total daily dose.20 Although the recommendation to provide two IQMs simultaneously is not a metric in itself, we reported it as the 12th IQM according to the analytical process involved in this study. In order to accurately report antibiotic use in the paediatric setting, the 12th metric could be particularly helpful.27 Reporting the quantity of antibiotic use by at least two different IQMs simultaneously gives a reporter an option to use a DDD-based metric as a measure of overall use per unit population accompanied by any of the other proposed IQMs that would best fit the investigator’s requirements and the aim of the reported data, frequently describing an individual, patient-level pattern of antibiotic use.

Stakeholders involved in this survey also chose case-mix index (CMI) as a denominator with DDDS as one of the 12 proposed IQMs. CMI is used as a risk adjustment for antibiotic utilization across different institutions.28–30 Considering the confounding effect of different wards and intra- and inter-institutional patient characteristics, the proposed IQM, DDDS/100 bed-days (BDs) per DOT may help to overcome this barrier and render the measurement of antibiotic use more realistic. Haug et al.31 and Rajmokan et al.32 emphasized that there is no consistent definition and index of CMI. Thus, we recommend that a definition of CMI should be clearly specified in studies involving this indicator.28,29 Morris et al.33 used a somewhat similar methodological approach to assess IQMs that are used to evaluate the impact of antimicrobial stewardship programmes and serve for public reporting. Potential for selection bias in the measures presented for evaluation to the expert panel and the lack of detailed reporting regarding all steps of the systematic review process present important limitations of their study.24 There are also a few other studies that described advantages and disadvantages of commonly used IQMs for antibiotic use that were highlighted by the participants in our consensus procedure.15,34,35 Many factors are recognized as influencing reliable reporting and comparison of antibiotic use worldwide. Different electronic prescribing modules use different filters for data extraction; pharmacy sales data aggregated over short registration intervals may significantly differ from ward stock accounting for the same period; risk adjustment of antibiotic use for patient mix and severity of illness is important.23,31,32,35,36 Metrics describing costs and other low-informative metrics (e.g. DDDs/day; minimum marketed dose; average number of antibiotics per prescription) generated through a systematic review process were both regarded as non-relevant by stakeholder assessment and previous studies.24,37 Definitions of involved IQMs for antibiotic use and data sources have an important effect on published results concerning the volume of antibiotic use.25,38 Consistency across definitions and quantity measures used in surveys should be synchronized worldwide and we promote this by providing a complete list of definitions of IQM numerators used internationally and emphasizing specific terms for IQMs. We propose to use the abbreviation ‘DOT’ only for days of therapy, excluding other terms abbreviated to DOT in the literature (Table 1). Another proposal that has arisen from this consensus process is that denominators should be clearly defined. It should be clearly stated whether the calculation of number of admissions and discharges between different departments within one hospital include only 1 day of hospitalization.39 Also, it is important to state whether patient-days are calculated based on calendar days or passages of midnight. Data sources (e.g. dispensing pharmacies data), including also specific providers of data (e.g. manufacturers, wholesalers, pharmacies) should be clearly specified to achieve more realistic insight.25 Kuster et al.39 have made recommendations for reporting methodological information for clear standardized reporting on hospital antibiotic use.

**Table 3.** The final set of 12 evidence-based and consensually validated quantity metrics for antibiotic use in the inpatient setting

| Inpatient quantity metric (IQM) | Description |
|---------------------------------|-------------|
| IQM 1: Defined daily doses (DDDs) per 100 patient-days (PDs)/bed-days (BDs)/occupied bed-days (OBDs) | numerator |
| IQM 2: Defined daily doses (DDDs) per admission | numerator |
| IQM 3: Defined daily doses (DDDs) per (100 bed-days per patient) | numerator |
| IQM 4: Prescribed daily doses (PDDs) per 100 PDs | numerator |
| IQM 5: Days of therapy (DOT) per patient | numerator |
| IQM 6: Days of therapy (DOT) per admission | numerator |
| IQM 7: Days of therapy (DOT) per discharge | numerator |
| IQM 8: Length of therapy (LOT) per patient | numerator |
| IQM 9: Length of therapy (LOT) per admission | numerator |
| IQM 10: Patients exposed to antibiotics per admission | numerator |
| IQM 11: Patients exposed to antibiotics per discharge | numerator |
| IQM 12: Antibiotic use should be preferably expressed in at least two metrics simultaneously | denominator |

a100(0) patient-days (PDs)/bed-days (BDs)/occupied bed-days (OBDs).
bCMI, case mix index. This is a relative value assigned to a diagnosis-related group of patients in a medical care environment.
One of the strengths of this study is our methodological approach involving a comprehensive four step RAND-modified Delphi procedure (systematic review, first online survey, consensus meeting and second online survey) in which international multidisciplinary representatives of all concerned stakeholders participated. Both online surveys had a higher response rate (44% and 88%) than what is observed on average.34–42 Both online surveys included a wide range of stakeholders from the medical community, from patients and public health, from the pharmaceutical industry, and from payers, policy makers, government and regulators. One limitation is that the systematic review process was limited to only one database (MEDLINE), although it was accompanied by a citation-tracking search and the review of 26 relevant web sites. The web site search included the most relevant ones, but not all. One could interpret it as a limitation of this study, but the web site search should rather be seen as complementary to the systematic literature review. It was performed to make sure no metrics were missed in the literature. Initial arbitrary selection of stakeholders could be considered a limitation of this study, but all groups were well represented. The recommendation to report antibiotic use with at least two different quantity metrics does not indicate which ones are preferred; this could be a strength and a limitation simultaneously.

**Conclusions**

Standardization of surveillance methods, including currently used IQMs, is crucial in order to improve stewardship measures and outcomes, including antibiotic resistance.36,43,44 Based on a comprehensive approach, a set of 12 IQMs on antibiotic use was generated that may serve for more accurate benchmarking practice. The last IQM, the recommendation ‘Antibiotic use should be preferably expressed in at least two metrics simultaneously’, constitutes a valuable new metric. The set of final metrics is a first step towards harmonized, internationally accepted reporting on the quantity of antibiotic use.

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**Figure 2.** Results of the four-step RAND-modified Delphi procedure.

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**Supplementary data**

Tables S1 to S5 and Figure S1 are available as Supplementary data at JAC Online.
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