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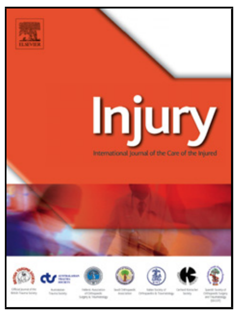

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Title

Classifying, measuring and improving the quality of data in trauma registries: a review of the literature

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Title

Classifying, measuring and improving the quality of data in trauma registries: a review of the literature

Key Words

trauma registry, trauma database, trauma databank, injury registry, injury database, injury databank, data quality, accuracy, completeness, capture.

Structured Abstract

Introduction

Globally, injury is a major cause of death and disability. Improvements in trauma care have been driven by trauma registries. The capacity of a trauma registry to inform improvements in the quality of trauma care is dependent upon the quality of data. The literature on data quality in disease registries is inconsistent and ambiguous; methods used for classifying, measuring, and improving data quality are not standardised. The aim of this study was to review the literature to determine the methods used to classify, measure and improve data quality in trauma registries.

Methods

A scoping review of the literature was performed. Databases were searched using the term “trauma registry’’ and its synonyms, combined with multiple terms denoting data quality. There was no restriction on year. Full-length manuscripts were included if the classification, measurement or improvement of data quality in one or more trauma registries was a study objective. Data were abstracted regarding registry demographics, study design, data quality classification, and the reported methods used to measure and improve the pre-defined data quality dimensions of accuracy, completeness and capture.

Results

Sixty-nine publications met the inclusion criteria. Four publications classified data quality. The most frequently described methods for measuring data accuracy (n=47) were checks against other datasets (n=18) and checks of injury coding (n=17). The most frequently described methods for measuring data completeness (n=47) were the percentage of included cases, for a given variable or list of variables, for which there was an observation in the registry (n=29). The most frequently described methods for measuring data capture (n=37) were the percentage of cases in a linked reference dataset that were also captured in the primary dataset being evaluated (n=24). Most publications dealing with the measurement of a dimension of data quality did not specify the methods used; most publications dealing with the improvement of data quality did not specify the dimension being targeted.

Conclusion

The classification, measurement and improvement of data quality in trauma registries is inconsistent. To maintain confidence in the usefulness of trauma registries, the metrics and reporting of data quality need to be standardised.

Manuscript

Introduction

Injury is a major cause of disability and death. The burden of injury is of particular concern amongst young and working-age adults and in developing countries[1]. In developed countries, trauma care systems have reduced morbidity and mortality from injury[2-8]. Improvements in the delivery of trauma care have been driven by the information contained in trauma registries, which are dedicated to storing data on the outcomes and processes of trauma care[9]. Trauma registries have played a very important role in developed trauma systems for more than thirty years[10]. Conversely, the use of trauma registries in developing countries, where the burden of injury is most prominent, remains sporadic[11,12].

The capacity of a trauma registry to inform improvements in the quality of trauma care depends upon the quality of its data. Incomplete and erroneous data are a threat to the use of trauma registries for comparing and benchmarking systems of trauma care[10,13]. If the quality of data in a trauma registry is unknown, questionable or poor, it will be rendered less valuable as a tool for improving the quality of trauma care. Systems of trauma care, at the single-hospital or multi-hospital level, need methods to measure and improve the quality of new or established trauma registries; users of observational research based on registry data need to be confident of the quality of the source data.[14]

For trauma registries, there is no single definition or classification of data quality. Amongst datasets in general, the taxonomy of data quality varies considerably according to the type and intended use of the dataset being considered[15-21]. For example, one publication defined data quality as “fitness for purpose” and listed its six dimensions as: relevance, accuracy and reliability, timeliness, accessibility, interpretability and coherence[15]. Another publication listed seven dimensions of data quality: valid, complete, consistent, unique, timely, accurate and precise[16]. Wang and Strong, in their iterative approach to developing a framework of data quality grouped a total of 15 dimensions under four categories of data quality: intrinsic, contextual, representational and accessibility[17].

The literature dealing with data quality amongst *health*-related datasets is similarly inconsistent[18-19]. Several publications have provided a relatively simple set of definitions and classification for data quality[20,21]. Sorensen et al included accuracy and completeness of variables, and completeness of registration, amongst their list of dimensions[20]. Similarly, Arts et al noted that the two most cited data quality attributes are accuracy (the extent to which registered data are in conformity to the truth) and completeness (the extent to which all necessary data that could have been registered have actually been registered)[21].

The aim of this study was to review the accessible literature to determine the methods used to classify, measure and improve data quality in trauma registries.

Methods

A scoping review of the literature was performed. Abstracts were sourced by searching MEDLINE, Embase and CINAHL databases on 12 February 2015. There were no year restrictions placed on the search. Key words used for the search were: ‘‘trauma registry’’, ‘‘trauma registries’’, ‘‘trauma database*’’, ‘‘trauma databank*’’, ‘‘injury registry’’, ‘‘injury registries’’, ‘‘injury database*’’, and ‘‘injury databank*’’. An additional subject heading search was undertaken in: MEDLINE using ‘‘Wounds and Injuries’’ AND ‘‘Registries’’; Embase using ‘‘Registry’’ AND ‘‘Injury’’ OR “Trauma”; and CINAHL using ‘‘Registries, Trauma’’. Finally, in each database, the results of the search strategy described above were combined (using “AND”) with each of the keywords denoting data quality and its dimensions in previous literature[15-21] (see Table 1).

From the results of the search, the authors included those full-length manuscripts which met the following criteria:

1. The trauma registry was a dedicated database, prospectively collecting data regarding injured patients at one or more health facilities, and
2. The classification, measurement or improvement of data quality in one or more trauma registries was a study objective.

Data on the following were abstracted from each full-text manuscript:

1. Characteristics of the trauma registry (source country, level of country development, jurisdiction, stage of registry existence)[22]
2. Characteristics of the publication (year published, study design)
3. Did the publication provide a classification of data quality?
4. Did the study of trauma registry data quality deal with measuring data quality *or* improving data quality *or* both?
5. What dimensions of trauma registry data quality were named?
6. For those publications dealing with measuring data quality, what dimensions of data quality were measured, how were the measurements defined and what specific metrics were used?
7. For those publications dealing with the improvement of data quality, what dimensions of data quality were targeted and what domains of trauma registry function were described?

For the final question of the trauma registry domains described in publications looking at *improving* data quality (7), a modified version of the Trauma Registry Assessment Tool was used[11,12,23]. The details of this tool and its validation have been published elsewhere[12]. Under the broad headings of physical resources, human resources and processes it comprises a checklist of the key components or domains which are generic to any trauma registry. The tool has previously been used to capture information on these domains of trauma registries, regardless of their context[11,12,23].

For the final two questions listed above (6 and 7), three key dimensions of data quality were chosen on the basis of being commonly cited in the disease registry literature and most clearly defined[20,21]. For the purposes of this review, they were defined by the authors by merging the approaches of Sorensen et al and Arts et al[20,21].

1. Accuracy: the extent to which registered data are in conformity with the truth
(i.e. How true is the value of an observation or the content of a cell in a spreadsheet of data, compared to a gold standard?)
2. Completeness: the extent to which all necessary data have been registered on registered cases
(i.e. Is there an observation for a variable on a registered case?)
3. Capture: the extent to which all necessary cases that could have been registered have actually been registered
(i.e. How complete is the case ascertainment, given the registry inclusion criteria?)

Dimensions of data quality which did not fit under these headings were also recorded and grouped under the heading “Other”.

Results

The initial search yielded 147 abstracts; 69 full text manuscripts matched the pre-defined inclusion criteria[24-92]. Of the 78 excluded publications, 69 did not have the classification, measurement or improvement of data quality of a trauma registry as a study objective. For 8 of the excluded publications, no full text journal article existed (mostly published conference abstracts). One potentially eligible abstract was excluded because the full text version was not available in English[93].

Although still few in number, the frequency of publications focusing on data quality in trauma registries has increased gradually over time, especially since 1998 (Figure 1). Almost half of the publications were from the US (n=34). Six of the seven publications from a trauma registry based in a developing country (level of development: 2, 3 or 4) were published after 2011. Most publications (n=44) were sourced from multi-hospital registries. More than one quarter of publications (n=18) dealt with data quality in the context of trauma registry establishment or feasibility. The aforementioned results are detailed for each publication in Supplementary File 1.

There were two perspectives of data quality in trauma registries and one literature review which conducted an audit of study methods and approaches to reporting and dealing with missing data in a multi-centre trauma registry[38,48,53]. Four of the 69 publications provided a general definition or classification of at least one data quality dimension[49,56,62,85]. Gomez et al defined “case ascertainment” as “systematic differences in the types of patients captured in registries”[49]. Alexandrescu et al referenced Arts et al for the afore-mentioned definitions of accuracy and completeness[21,56]. Data quality was defined as “the totality of features and characteristics of a data set that bear on its ability to satisfy the needs that result from the intended use of the data”[21,56]. Hlaing et al classified “errors” into seven groups: “Out-of-Range Time Values”, “False Positive and False Negative Coding Errors”, “Errors of Commission or Omission”, “Duplication of Data”, “Errors in Demographic Data”, “Errors Because of Inconsistency in Coding” and “Errors Because of Incongruence in Coding”[62]. Meeuwisse et al referenced the USA Centers for Disease Control in its approach to classifying and defining the attributes of a surveillance system: simplicity (in structure and ease of use), flexibility (to adapt to changes), acceptability (the willingness of individuals to participate), sensitivity (the proportion of cases detected), predictive value positive (the proportion detected who actually have the condition under surveillance), representativeness (occurrence over time and distribution) and timeliness (speed or delay between steps)[85,94].

All of the publications studied either the measurement (n=67) or improvement (n=62) of data quality. Almost all (n=68) of the publications covered at least one of the key dimensions of accuracy (n=49), completeness (n=48), or capture (n=38); most dealt with at least one other dimension of data quality (n=44). The aforementioned results are detailed for each publication in Supplementary File 2.

There were at least 120 different names for dimensions of data quality used in the 69 publications (Table 2); 83 of these described dimensions other than accuracy, completeness and capture.

Table 3 and 4 provide in detail the approaches used or described in measuring (Table 3) and improving (Table 4) data quality in one or more trauma registries.

Accuracy

In most of the publications (n=47) one or more different methods used to evaluate trauma registry accuracy were described. Simpler methods, which could be applied without additional data, included checks of internal consistency (whether an observation on one variable had a logical relationship with an observation on another related variable) (n=7) and domain checks (whether an observation on one variable was plausible) (n=3). More extensive checks included the evaluation of the inter-rater reliability among data collectors or coders (n=10). Additional approaches to evaluating accuracy included linking with other data sources of the same population (n=18) and verification against the source data (n=6). Where a “gold standard” was defined, measures of sensitivity and specificity were used; otherwise measures of agreement (e.g. kappa statistic for categorical data; Bland-Altman plot for numerical data) were used. In more than a quarter of the publications considering the evaluation of accuracy, no method was specified (n=13) (Table 3).

Some publications were particularly noteworthy in that they clearly demonstrated the measurement of data accuracy using one or more of the methods described in the previous paragraph[39,59,72]. Beretta et al performed checks of internal consistency, using the example of "ICP (intracranial pressure) lower than 20 mmHg in a patient without ICP monitoring" and domain, using the example of "hemoglobin oxygen saturation more than 100%"[59]. Read-Allsop et al evaluated inter-rater reliability for AIS (Abbreviated Injury Scale) coding[72]. Following linkage between datasets, Newgard et al first performed checks of internal consistency and domain and then reported accuracy by measuring against an alternative database (sensitivity, specificity, exact agreement, median difference), followed by measures of agreement (kappa, modified kappa, Bland-Altman plot and Intraclass Correlation Coefficient)[39].

Few publications dealt with methods which specifically targeted the improvement of data accuracy. Comprehensive approaches to the training and feedback of staff involved in data collection, coding and input were provided by Auerbach et al and Read-Allsop et al[72,74]. Protetch et al and Beretta et al identified the importance of integrating validation tools (checks of internal consistency and domain) into registry computer sofware[52,59].

Completeness

The majority of publications evaluating data completeness (n=47) measured this as the percentage of included cases, for a given variable or list of variables, for which there was an observation in the registry (n=32). There were several publications, demonstrating the measurement of data completeness in a trauma registry, which were notable for their high level of detail[24,39,41]. Ringdal et al provided a benchmark level of completeness of 80%, but stressed that this was an arbitrarily chosen threshold and that "no justifications or guidelines for the acceptability of missing data in registry studies exist"[41]. Nottidge et al provided a detailed evaluation of data completeness in a feasibility study of a registry in Nigeria[24].

A number of the more recent publications examined approaches to handling missing data at the analysis stage, including multiple imputation (MI). MI uses the relationship between variables in collected data to estimate the distribution of the missing observations. Amongst the six publications focused upon improving data completeness for analysis, MI was promoted as the preferred method, but not as a remedy for the important step of rigorous data collection[36,38,46,48,55,65].

Capture

There were fewer publications dealing with evaluating case capture when compared to accuracy or completeness (n=37). The most commonly used approach was to link and compare different datasets (n=27). Capture was generally measured as the percentage of cases in the reference dataset that were also captured in the primary dataset being evaluated. Notable examples demonstrating the measurement of data capture using percentage of a reference dataset, were Newgard et al, Schootman et al and Goldberg et al[43,80,91]

Few publications were dedicated to methods of improving data capture at the data collection stage. One such publication was Wainiqolo et al[34], which provided in detail the implementation of supervision, cross-checking with hospital administrative records, and data collector feedback to improve data capture. Specific statistical methods to improve data capture in trauma registries operated concurrently with the methods used to measure data capture. Linkage methods were either “deterministic”[87], where cases were merged if there was an exact match (unlikely), or “probabilistic”[39,43,83,87](preferred), where various weights were applied according to the level of matching. Working in tandem with dataset linkage, “capture-recapture” methods were used to estimate the eligible population and the proportion of these eligible cases actually included in the registry[32,43,80,83,86,87]. One publication urged caution on the capture-recapture approach, on the basis that the necessary assumption of dataset independence was flawed[78].

Linkage methods primarily used to improve data capture were also used to improve data accuracy and completeness[32].

Other data quality domains

Five of the 42 publications dealing with the measurement of a data quality dimension other than accuracy, completeness or capture, actually specified the methods used. Ringdal et al measured “feasibility”, “attainability” and “difficulty” of data collection using a written questionnaire[41]. Scheetz et al measured “accessibility” and “usefulness” by recording the response rate to written requests for data[54]. Meeuwisse1998 measured “usefulness” with a written questionnaire[85]. Laing et al measured “user satisfaction” and the “ease” and “timeliness” of data entry[27]. Wargo et al also measured “timeliness”, but of registry staff activities, including case completion[28].

Very few publications were specific regarding methods used to improve “other” dimensions of data quality. Wargo et al provided a detailed account of approaches to improve productivity and timeliness, whilst maintaining data accuracy[28].

Discussion

This study examined the peer-reviewed literature to determine approaches to the definition, classification, standardisation, measurement, improvement and reporting of data quality in a trauma registry. Most publications focusing on data quality were based on trauma registries in developed countries and many were large multi-hospital registries.

There were just four studies which provided a general definition or classification of data quality in trauma registries, amongst which the taxonomy was inconsistent. Most of the publications covered at least one of the key data quality dimensions: accuracy, completeness and capture. Most of the publications also considered at least one other data quality dimension. A closer examination of Table 2 generated the following potential candidates for other dimensions: “usefulness” (utility, usability), “timeliness” (efficiency), “comparability” (standardisation) and “cost-effectiveness”.

Approximately one quarter of publications which considered the measurement of accuracy, completeness or capture, did not specify the method or indicator used. The vast majority of publications dealing with the measurement of at least one “other” dimension did not specify the method or indicator used. While most publications focused on improving data quality, few provided detail regarding which methods were linked to which dimensions of data quality.

Described approaches to *measuring* data accuracy varied considerably, from the relatively simple approaches of consistency and domain checks, through monitoring of coding reliability and agreement with other databases, to source data verification. For source data verification, the patient medical record remains the best source, or “gold standard”, although completeness cannot be assured. Specific methods targeting the *improvement* of data accuracy were rarely provided in detail. Approaches to *measuring* data completeness, namely measuring the percentage of cases with complete observations for each variable, were more uniform and more widely described, implemented and reported. Specifically described methods to *improve* data completeness were mostly statistical approaches, namely MI. The published approaches to *measuring* and *improving* data capture largely involved the linkage of alternative datasets, but is dependent upon the existence and accessibility of such alternative datasets. The best approaches to *improving* data capture are the practical interventions intended to also *improve* accuracy and completeness such as developing efficient feedback mechanisms with data collection staff.

Rigorous attention to data quality in trauma registries is critically important to the valid benchmarking of trauma systems. How data quality is managed can have a very large impact on trauma system evaluation and health policy[36,38,46,53,60,95]. This recognition of the paramount importance of data quality is not new[90,91] and it is not confined to trauma registries[96]. But to date, there has been no single accessible document in the published peer-reviewed medical literature dealing with the definitions, dimensions, standards, evaluation, improvement or reporting of data quality in a trauma registry. Furthermore, even where interventions for improving specific dimensions of data quality have been thoroughly tested and published, the evidence of widespread adoption as best practice remains sparse[46,65,96].

While the non-trauma literature has provided a resource for describing the range of data quality dimensions, it is inconsistent with regard to the definition and classification of data quality. It may be that trauma registries need a specific framework to classify data quality. Unless there is clarity on the matter of classification, the progress towards developing a simple approach and metric to evaluating data quality in trauma registries will be slow. In turn, achieving the capacity to universally *measure* data quality in trauma registries will allow the focus to shift to the best interventions to *improve* data quality. Finally, to allow confidence in the results commonly generated from the growing number of trauma registries, there needs to be a uniform and universal standard for reporting trauma registry data quality. In the absence of standards for trauma registry data quality, the adoption of registry-derived initiatives to improve the quality of *trauma care* will be slowed.

Although the term “feasibility” or “pilot” was not included in the search strategy, more than one quarter of the publications dealing with data quality in trauma registries, including six of the seven publications from developing countries, were feasibility studies, mostly by self-identification. The definition of feasibility is not entirely clear, but implies, in the event of establishing a trauma registry, the very basic entry point of the data quality spectrum, where there has been the “successful” collection, and reporting, of *some* data on *some* variables for *some* patients. For those looking to start a successful and high quality trauma registry, there is no universally accessible standardised checklist.

Proper attention to ensure data quality to inform improvements in trauma care is critically important on a global scale. One of the five pillars of The United Nations' "Global Plan" for the current "Decade of Action for Road Safety 2011-2020" is "Post crash response". Activities encouraged include Activity 2: "Develop hospital trauma care systems and evaluate the quality of care through the implementation of good practices on trauma care systems and quality assurance" and Activity 7: "Encourage research and development into improving post crash response"[97]. To support these activities, there needs to be a global standardisation of trauma registry functions, including a global minimum dataset and dictionary, uniform approaches to risk adjustment and the standardisation of data quality monitoring and reporting. Furthermore, this standardisation must account for the resource challenges of the vast majority of countries for which the burden of injury is greatest.[98-100].

This study has some limitations. The impetus for the study question and review included the ambiguity regarding the definition and classification of data quality in trauma registries. This same ambiguity necessarily provided challenges in sampling, and analysing, the literature methodically. Some informative publications may have been missed, including documents dealing with the broader remit of trauma centre verifcation[101-103]. The intention was to focus upon the content of peer-reviewed publications which were widely accessible in the medical literature and contained a specific focus upon data quality. Given the study purpose and the challenges of defining and classifying data quality, the use of a scoping review methodology was considered ideal.[104-105]

That these limitations exist heightens the need to develop a comprehensive literature on data quality in trauma registries. This study addressed the question of "how" data quality is defined, classified, measured and improved. A logical next step, sampling all trauma registry-based publications over a recent period, would be to examine "if" data quality is reported and "what" is the result of data quality measurement. Such an audit of data quality would require a checklist or scorecard, potentially informed by this scoping review. Only through the development of accessible published documents, informed by both consensus and evidence, will there be the necessary standardised guidance for the evaluation and improvement of data quality in trauma registries, and the concomitant improvement in the quality of trauma care.

Conclusion

The definition and classification of trauma registry data quality is ambiguous. Publications dealing with the evaluation and improvement of data quality in trauma registries are limited in number, consistency of approach and detail. To maintain the confidence of clinicians and administrators in the usefulness of trauma registries for monitoring the quality of trauma care, the metrics and reporting of data quality need to be standardised. There is a clear need for additional research and a globally accessible document standardising the definition, classification, measurement, improvement and reporting of data quality in trauma registries. Publications of trauma-registry-based studies must, as a minimum, report on data accuracy, completeness and capture.

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Table 1: Dimensions of quality used in search terms

Figure 1: Number of publications by year

Table 2: Dimensions of data quality named in publications

Table 3: Approaches to measuring data quality by dimension

Table 4: Approaches to improving data quality (accuracy, completeness and/or capture)

Supplementary File 1: Included publications, by year of publication, source country, level of country development, registry jurisdiction and level of registry development.

Supplemetary File 2: Description of publications by study design, study question and data quality dimension

Table 1: Dimensions of quality used in search terms

quality	Correctness	comparability
accuracy	consistency	uniqueness
completeness	usability	availability
capture	relevance	representativeness
coverage	timeliness	case ascertainment
missing	accessibility	error
reliability	interpretability	concordance
validity	coherence	precision
	verification	

Figure 1: Number of publications by year

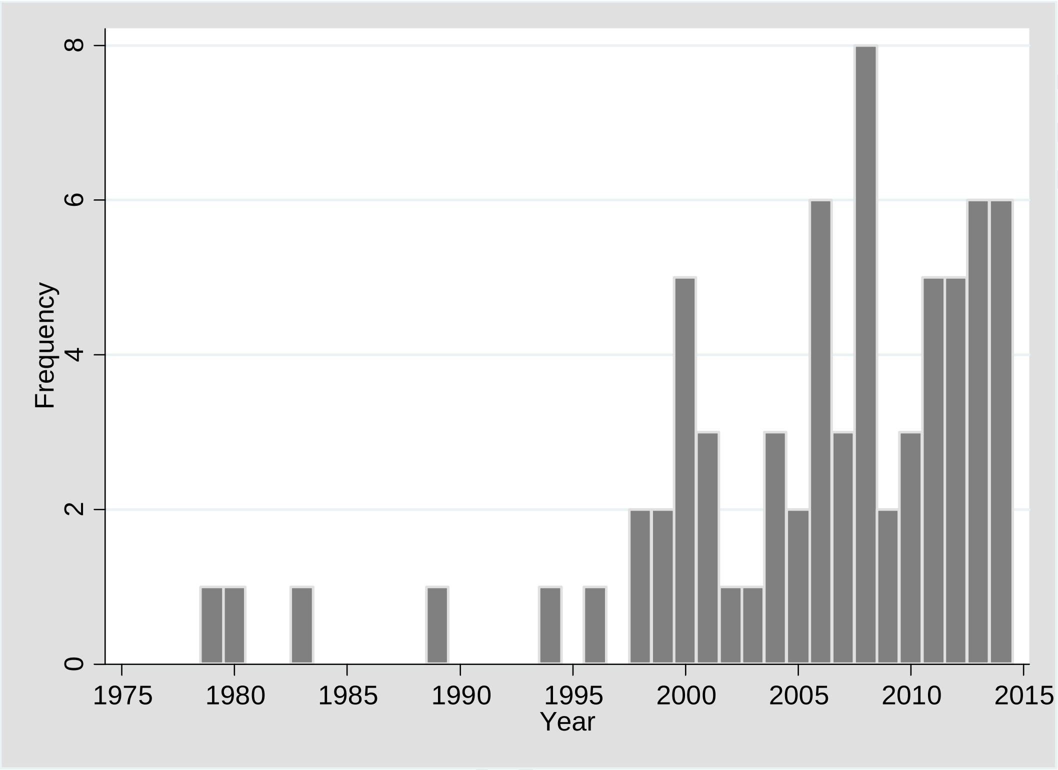

Table 2: Dimensions of data quality named in publications

	Accuracy	
Consistency	Variances	Misclassification
Errors	Reproducibility	Replicable
Validity	Precision	Noise
Differences	Agreement	Bias
Discrepancies	Verification	Logical
Variability	Sensitivity	Matching
Reliability	Concordance	Sloppy
Congruence	Misreporting	Commission
Homogeneity	Miscoding	Mistakes
Correctness	Out of range	Contradictory
Flawed	Confidence	Certainty
	Completeness	
Dropouts	Missingness	Collectability
Omissions	Blank	Empty
	Capture	
Completeness	Representativeness	Coverage
Case ascertainment	Over-reported	Under-reported
Generalisability	Omissions	Missing
	Duplication	
	Other	
Importance	Accessibility	Timeliness
Relevance	Flexibility	Labour-intensive
Ease	Manageability	Credibility
Sustainability	Time-consuming	Deficiencies
Detail	Descriptive	Shortcomings
Usefulness	Promptness	Misleading
Efficiency	Acceptability	Real-time
Functionality	Value	Feasibility
Utility	Meaningful	Versatility
Standardisation	Simplicity	Optimal
Uniformity	Availability	Continuity
Integrity	User-friendly	Effectiveness
Comparability	Usability	Rigour
Lacking	Comprehensive	Indispensable
Applicability	Flow	Interpretability
Limitations	Granularity	Inexpensive
Scope	Cleanliness	Advantageous
Range	Attainability	Desirability
Nonsensible	Difficulty	Compliance
Cost-effectiveness	Value-add	Robustness
Misinformation	Contribute	Productivity
Maintenance	Performance	Satisfactory
Obscurity	Current	Speed
Informative	Adequacy	Ideal
Professional	Veracity	Compatibility
Stability	Security	Convenience
Excellence	Failure	Suitability
	Appropriateness	

Table 3: Approaches to measuring data quality by dimension

Dimension	Method[a] (of measurement used)	Number of publications	Indicator[a] (used to measure dimension)	Number of publications	References
Accuracy (n=47)	Source data verification	6	Sensitivity / specificity / accuracy (%)	4	44,52,60,85
			Unspecified	2	34,56
	Validation – other datasets	18	Sensitivity / specificity / accuracy (%)	11	32,39,42,45,62,68,70,77,81,85,86
			Agreement (e.g. kappa / ICC / Bland Altman plot)	4	26,39,45,65
			Unspecified	5	43,56,83,84,87
	Coding verification	17	Sensitivity / specificity / accuracy (%)	9	41,42,45,52,62,72,73,77,81
			Agreement (e.g. kappa)	2	40,72
			Unspecified	7	31,34,53,56,75,81,88
	Internal consistency check	7	Proportion of cases for a variable (%)	4	25,33,59,62
			Unspecified	3	39,54,56
	Domain check	3	Proportion of observations outside plausible range (%)	1	62
			Unspecified	2	39,59
	Inter-rater reliability	10	Proportion of observations in agreement (%)	3	25,72,85
			Kappa	1	26
			Unspecified	6	52,53,54,73,84,88
	Unspecified	13	-	13	27,28,30,38,51,57,58,61,72,76, 79,89,92
Completeness (n=47)	Completeness of variables	32	% of cases with complete observations for *each* variable	29	24,27,29,31,32,33-36,39,41,43,46,47,48,54-57,59,60,62,64,65,71,76,77,81,85
			Unspecified	3	30,44,53
	Completeness of cases	10	% of cases with complete observations for *all* variables	9	25,36,42,46,60,63,64,71,76
			Unspecified	1	68
	Unspecified	11	-	11	26,38,51,52,58,61,67,83,87,89,92
Capture (n=37)	Linkages – other datasets	27	% of eligible population included in registry	24	24,27,32,34,39,42,43,45,56,63,67-70,77,78,80,81,83,85-87,90,91
			Unspecified	3	30,60,62
	Comparison of distributions	3	Difference in means / other	3	49,67,81
			Unspecified	0	-
	Case duplication	6	Number (%) or cases with more than one record	4	32,33,34,62
			Unspecified	2	39,42
	Unspecified	9	-	9	29,31,38,51,53,61,66,79,92
Other (n=42)	Specified[b]	5	-	5	27,28,41,54,85
	Unspecified	37	-	37	24,25,26,30,31,33,34,37,40,43,45,47, 52,53,56,58-61,64,66,67,70,73-77,79,82,83,84,87,88,90-92

[a] Not mutually exclusive (except "unspecified). i.e. There may be more than one measurement method or indicator in a single publication

[b] Described in the results section

Table 4: Approaches to improving data quality (accuracy, completeness and/or capture)

Domain	**Items**	**Primary dimension(s)**			**Number of papers (n=69)**	**References**
		Accuracy	Complete	Capture		
Physical Resources						
Equipment	Computer hardware	x	x	x	9	24,27,30,37,61,74,79,88,92
	Computer software	x	x	x	26	25,27,29-31,33,34,37,39,43,51-53,58,59,61,62,74-76,79,82,83,87-89
Human resources						
Staff – numbers		x	x	x	7	28,30,37,59,63,88,91
Staff – type / mix		x	x	x	19	27,30,33,34,37,61-63,73-76,79,82,85,88,89,91,92
Staff – training		x	x	x	21	27,30,33,34,37,45,52,53,59,62,63,68,72,73-75,84,85,88,91,92
Processes						
Administration	Ethics / consent	-	-	x	11	30,52-54,61,62,74,79,82,90,91
	Supervision	x	x	x	6	30,34,52,53,59,62
	Feedback	x	x	x	16	25,28,30,34,37,52,53,59,62,68,73,74,79,82,85,88
	Financial incentives / penalties	x	x	x	4	31,52,74,90
Organisation						
Inclusion criteria		-	-	x	22	27,31,32,34,39,45,53,56,61,66-68,70,76,79,80,83,84,86,88,91,92
Variables	Selection (minimum dataset)	x	x	-	33	24,26,27,30-32,34,37,39,43,45,48,51-54,56,58,59,61-65,76,79,82,84,85,87-89,91
	Definition / coding	x	x	x	19	25,26,30,34,42,51,53,54,57,59,61,66,67,74,80,84,88,90,92
Data capture	Form	x	x	-	12	24,30,34,59,62,63,66,79,85,88,89,92
	Collector type	x	x	-	15	24-27,30,31,34,37,62,70,73,79,85,88,92
	Collection mechanism	x	x	-	21	24,26-28,30,31,34,37,39,48,51,57,59,62,70,73,74,79,84,85,88
	Coding (e.g. ICD /AIS)	x	-	x	23	25,31,34,40,42,45,52-54,58,62,67,68,72,73,75,77,79,80,83,84,88,92
	Input	x	x	x	17	24,30,32,33,37,39,43,51,53,57-59,61,74,75,82,84
	Linkages	x	x	x	24	29-32,39,43,45,50,51,53,54,61,67-70,77,78,80,82,83,86,87,91
	Missing data[a]	-	x	-	15	26,29,35,36,38,39,43,46,48,53-55,64,65,71

[a] Missing data methods at analysis stage: includes complete case analysis, single imputation, multiple imputation

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Classifying, measuring and improving the quality of data in trauma registries: a review of the literature

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