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The European Network of Centres for Pharmacoepidemiology and Pharmacovigilance (ENCEPP)

Guide on Methodological Standards in Pharmacoepidemiology (Revision 6)

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1. Introduction

The choice of epidemiological methods to answer a research question is based on principles rather than on rules, but certain standards are needed to assure validity and robustness of the study results. Textbooks describing methodological standards in pharmacoepidemiological research are numerous but cannot follow new developments in research. ENCePP therefore considered there was a need for a regularly updated resource providing recommendations on the practical implementation of pharmacoepidemiological principles and innovative methods, based on published guidance and illustrative examples.

This Guide aims to offer a dynamic and publicly available web resource for methodological English language guidance in pharmacoepidemiology. It provides links to selected published articles and guidelines that illustrate important principles of pharmacoepidemiological research. For each topic covered, recommendations are provided with direct electronic access to textbooks, reference documents and examples chosen by experts from ENCePP. Where relevant, gaps in existing guidance are addressed with what ENCePP considers as being good practice. The Guide is updated annually by structured review to maintain its dynamic nature. It may also be amended as necessary in response to comments received. For these purposes, any comment and additional relevant guidance document may be forwarded to encepp_comments@ema.europa.eu.

The Guide does not discuss general methods of pharmacoepidemiology already covered in existing textbooks. For example, it does not describe traditional study designs like the cross-sectional, cohort and case-control designs but it discusses important aspects of more recent designs such as the self-controlled case series (SCCS) design. Chapters 1 to 9 describe methods that may be used in studies with different goals, be they safety, effectiveness, drug utilisation, health technology assessment or any other objective. For some specific topics, specific recommendations and references are provided where they differ from general principles. Chapter 10 provides more extensive guidance on three specific topics, comparative effectiveness research, vaccine safety and effectiveness and pharmacogenetic studies. This chapter may be expanded in future revisions if there is a need for methodological guidance on other topics.

Annex 1 has been developed separately by an ENCePP working group to provide methodological guidance addressing the conduct of systematic reviews and meta-analyses of drug safety endpoints generated in completed (published or unpublished) comparative pharmacoepidemiological studies.

General guidance on the conduct of pharmacoepidemiology studies can be found in the [ISPE Good Pharmacoepidemiology Practices \(GPP\)](#) and the [IEA Good Epidemiology Practice \(GEP\)](#). The GPP is especially useful for its recommendations on aspects rarely covered by guidelines, such as data quality issues and archiving. The EU legislation ([Directive 2001/83/EU](#)) includes the possibility for regulatory authorities to impose on marketing authorisation holders the conduct of post-authorisation safety study (PASS) as a condition of the marketing authorisation, a PASS being defined as 'any study relating to an authorised medicinal product conducted with the aim of identifying, characterising or quantifying a safety hazard, confirming the safety profile of the medicinal product, or of measuring the effectiveness of risk management measures.' The [Guideline of good pharmacovigilance practices \(GVP\) Module VIII - Post-authorisation safety studies](#) provides a general guidance on the development, conduct and reporting of PASS conducted by marketing authorisation holders voluntarily or pursuant to an obligation. It also describes the criteria applicable in the European Union (EU) to define a post-authorisation study as non-interventional, but investigators should be aware that such criteria are sometimes interpreted differently at national level in different EU countries.

The following list proposes a list of textbooks on standard methods in pharmacoepidemiology recommended for consultation. The list is not exhaustive, as researchers may find other textbooks more appropriate to their specific needs and others are cited in specific chapters.

- Epidemiology: Principles and Methods 2nd Edition (B. MacMahon, D. Trichopoulos. Lippincott Williams & Wilkins, 1996) offers an introductory understanding of epidemiological methods and processes, including on study designs and control for confounding.
- Modern Epidemiology 3rd Edition (K. Rothman, S. Greenland, T. Lash. Lippincott Williams & Wilkins, 2008) serves as a comprehensive textbook on methods in epidemiology.
- Pharmacoepidemiology 5th Edition (B. Strom, S.E. Kimmel, S. Hennessy. Wiley, 2012) provides a complete review of epidemiological methods applied to the study of drugs.
- Pharmacoepidemiology and Therapeutic Risk Management 1st Edition (A.G. Hartzema, H.H. Tilson and K.A. Chan, Editors. Harvey Whitney Books Company, 2008). In addition to a general review of drug-specific methodologies, this textbook illustrates practical issues with a large number of real life examples.
- Encyclopedia of Epidemiologic Methods (M.H. Gail, J. Benichou, Editors. Wiley, 2000). This compilation of articles complements existing textbooks by providing a large coverage of specialised topics in epidemiological and statistical methods.
- Practical Statistics for Medical Research (D. Altman. Chapman & Hall, 1990) presents a problem-based statistical text for medical researchers.
- Drug Utilization Research. Methods of Applications (Elsevier M, Wettermark B, Almarsdóttir AB, et al. Editors. Wiley Blackwell, 2016). This book provides a comprehensive manual of methodology and applications of drug utilisation research.
- A Dictionary of Epidemiology 5th Edition (M Porta, Editor. J.M. Last S. Greenland, Associate Editors. Oxford University Press, 2008), sponsored by the International Epidemiological Association (IEA), provides a definition and concise explanation of epidemiologic terms and is a key to understanding epidemiological concepts.
- Dictionary of Pharmacoepidemiology (Bernard Bégaud. Wiley, 2000) illustrates definitions with practical examples and is particularly useful for pharmacovigilance aspects of pharmacoepidemiology.

2. Formulating the research question

Generating evidence involves three steps: asking the right research questions, finding or collecting the fit-for-purpose data, and conducting the appropriate analyses. The first step in any research is to formulate the research question clearly and accurately. The research question should specify the problem or gap in knowledge to be addressed and how it will be investigated in the proposed research. The research question should formulate the 'why' (main justification for starting the research), the 'what' (exposure and endpoints), the 'who' (target population), the 'how' (main study design) and the 'when' (time period of the study) of the research in a way that it helps understanding how it has guided the choice of study objectives and methods described in the protocol, such as the choice of the study population, data source(s), exposure or endpoints. It should make it clear whether a hypothesis will be tested and in this case whether the hypothesis is pre-specified or data driven. The research question should also state who will be the primary end-users of the study results (e.g. regulators or public health authorities, health technology assessment organisations, payers, pharmaceutical company, research community).

Previous findings are useful for the methodological planning of the current study and may support the background, research question, hypotheses and design of the proposed study. They may also serve to determine the expected effect size and, if available in the target population, to characterise risk factors for the event, to identify relevant outcomes and measures and to assess the feasibility of the proposed study. A critical and thorough review of the literature forms the basis for the theoretical framework of the research question and should usually be included in the background section of a protocol. Such a review aims to evaluate current evidence around the question at hand and identify gaps in knowledge that a study is intended to fill. [How to formulate research recommendations](#) (BMJ 2006;333:804-6) proposes the EPICOT format with 5 core elements (Evidence, Population, Intervention, Comparison, Outcome and Time stamp) for research recommendations on the effects of treatments following systematic reviews. This format was adopted by the European network of Health Technology Assessment (EUnetHTA) in its [Position paper on how to formulate research recommendations](#). Chapter 5.7 and Appendix 1 present methods for reviewing and synthesising findings from the literature through the means of systematic review and meta-analysis.

When the study data source is not well characterized or known for the purpose of a particular study, a feasibility study should be considered. The aim of a feasibility study is not to answer the research question directly but to determine whether the data source could answer it within the expected timelines and with the required statistical power for the proposed study design. Feasibility studies can provide information on the number of people with a specific exposure or outcome, the availability of covariates and the follow up period. A feasibility study can also provide insights into the potential difficulties which may be encountered in the conduct of the study or which may introduce bias. The ISPE [Good pharmacoepidemiology practice](#) (GPP) explains how a data collection method or data source can answer a research question with justifications coming from the feasibility study when relevant.

3. Development of the study protocol

The study protocol is the core document of a study that should be drafted as one of the first steps in any research project once the research question has been clearly defined. The final version must precisely describe everything being done in the study so that the study can be reproduced. It should be amended and updated as needed and amendments should be justified.

For PASS described in the [Guideline of good pharmacovigilance practices \(GVP\) Module VIII - Post-authorisation safety studies](#), the [Commission Implementing Regulation \(EU\) No 520/2012](#) provides legal definitions of the start of data collection (the date from which information on the first study subject is first recorded in the study dataset, or, in the case of secondary use of data, the date from which data extraction starts) and of the end of data collection (the date from which the analytical dataset is completely available). These dates provide timelines for the commencement of the study and the submission of the final study report to the competent authorities. It also provides the format of protocols, abstracts and final study reports for imposed PASS. Based on these formats, the European Medicines Agency (EMA) published detailed templates for the [protocol](#) and [final study report](#) which it recommends to be used for all PASS, including meta-analyses and systematic reviews. The [ISPE Guidelines for Good Pharmacoepidemiology Practices \(GPP\)](#) provides guidance on what is expected from a pharmacoepidemiology study protocol and on the different aspects to be covered. It states that the protocol should include a description of the data quality and integrity, including abstraction of original documents, extent of source data verification, and validation of endpoints. The [FDA's Best Practices for Conducting and Reporting Pharmacoepidemiologic Safety Studies Using Electronic Health Care Data Sets](#) includes a description of the elements that should be addressed in the protocols of such studies, including the choice of data sources and study population, the study design and the analyses. The [ENCePP](#)

[Checklist for Study Protocols](#) seeks to stimulate researchers to consider important epidemiological aspects when designing a pharmacoepidemiological study and writing a study protocol. The [Agency for Healthcare Research and Quality \(AHRO\)](#) published [Developing a Protocol for Observational Comparative Effectiveness Research: A User's Guide](#) including best practice principles and checklists on a wide range of topics that are also applicable to observational studies outside the scope of comparative effectiveness research. The Appendix 1 of the [CIOMS International Ethical Guidelines for Health-related Research Involving Humans](#) (Geneva: 2016) provides a list of 48 items to be included in a protocol or associated documents for health-related research involving humans.

It should be kept in mind that different regulators and stakeholders (e.g., data owners) might require different protocol structure from the one recommended by the above mentioned guidances and several versions of the protocol for the same study might be required.

The protocol should cover at least the following aspects:

- The research question the study is designed to answer, which might be purely descriptive, exploratory or explanatory (hypothesis driven). The protocol should include a background description that explains the origin (scientific, regulatory, etc.) and current knowledge on the research question. It will also explain the context of the research question, including what data are currently available and how these data can or cannot contribute to answering the question. The context will also be defined in terms of what information sources can be used to generate appropriate data and how the proposed study methodology will be shaped around these.
- The main study objective and possible secondary objectives, which are operational definitions of the research question. In defining secondary objectives, consideration could be given to time and cost, which may impose constraints and choices, for example in terms of sample size, duration of follow-up or data collection.
- The source and study population to be used to answer the research question. The protocol should describe whether this population is already identified, and whether data are already available (allowing a secondary data collection from a database) or whether it needs to be recruited de novo. The limits of the desired population will be defined, including inclusion/exclusion criteria, timelines (such as index dates for inclusion in the study) and any exposure criteria and events defining cases and exposed study groups.
- Exposure of interest that needs to be pre-specified and defined, including duration and intensity of exposure, source of data and methods of ascertainment.
- Outcomes of interest that need to be pre-specified and defined, including data sources, operational definitions and methods of ascertainment such as data elements in field studies or appropriate codes in database studies.
- Adverse events/reactions that will or will not be collected and reported and the procedures put in place for this purpose. In the EU, the collection and reporting of adverse events or reactions by companies sponsoring a post-authorisation study should follow the recommendations specified in [Module VI of the Guideline on good pharmacovigilance practice \(GVP\) - Management and reporting of adverse reactions to medicinal products](#). If the study qualifies as an interventional trial, the reporting criteria laid down in [Directive 2001/20/EC](#) and [Volume 10 of the Rules Governing Medicinal Products in the European Union](#) should be followed.
- The covariates and potential confounders that need to be pre-specified and defined, including how they will be measured.
- The statistical plan for the analysis of the resulting data, including statistical methods and software, adjustment strategies, and how the results are going to be presented.

- The identification and minimisation of potential biases.
- Major assumptions, critical uncertainties and challenges in the design, conduct and interpretation of the results of the study given the research question and the data used.
- Ethical considerations, as described in the section on governance of the current document.

The various data collection forms including the Case Report Form (CRF) or descriptions of the data elements may be appended to the protocol, providing an exact representation of how the data will be collected. The study protocols could include a section specifying ways in which the CRF will be piloted, tested and finalised. Amendments of final CRFs should be justified. For field studies, physician or patient forms would be included depending on the data collection methodology. Other forms may be included as needed, such as patient information or patient-oriented summaries.

4. Approaches to data collection

There are two main approaches for data collection: collection of data specifically for a particular study ('primary data collection') or use of data already collected for another purpose, e.g. as part of administrative records of patient health care ('secondary data collection'). The distinction between primary and secondary data collection is important for marketing authorisation holders as it implies different regulatory requirements for the collection and reporting of suspected adverse reactions, as described in [Module VI of the Guideline on good pharmacovigilance practice \(GVP\) - Management and reporting of adverse reactions to medicinal products](#).

Secondary data collection has become the most common approach used in pharmacoepidemiology due to the increasing availability of electronic healthcare records, administrative claims data and other already existing data sources (see section 4.2 Secondary data collection). In addition, networking between centres active in pharmacoepidemiology and pharmacovigilance is rapidly changing the landscape of drug safety research in Europe, both in terms of networks of data and networks of researchers who can contribute to a particular study with a particular data source (see section 4.6 Research Networks).

4.1. Primary data collection

Collection of specific data for a study has played an important role in pharmacoepidemiology and methodological aspects for the conduct of primary data collection studies are well covered in the textbooks and guidelines referred to in the Introduction section. Annex 1 of [Module VIII](#) of the Good pharmacovigilance practice provides includes examples of different study designs based on prospective primary data collection such as cross-sectional study, prospective cohort study, active surveillance, etc. Survey method and randomised controlled trials as examples of primary data collections are presented.

Studies using hospital or community-based primary data collection have allowed the evaluation of drug-disease associations for rare complex conditions that require very large source populations and in-depth case assessment by clinical experts. Classic examples are [Appetite-Suppressant Drugs and the Risk of Primary Pulmonary Hypertension](#) (N Engl J Med 1996; 335:609-16), [The design of a study of the drug etiology of agranulocytosis and aplastic anemia](#) (Eur J Clin Pharmacol 1983; 24:833-6) and [Medication Use and the Risk of Stevens–Johnson Syndrome or Toxic Epidermal Necrolysis](#) (N Engl J Med 1995; 333:1600-8). For some conditions, case-control surveillance networks have been developed and used for selected studies and for signal generation and clarification, e.g. [Signal generation and clarification: use of case-control data](#) (Pharmacoepidemiol Drug Saf 2001; 10:197-203).

4.1.1. Surveys

A survey is a data collection tool used to gather information about individuals. Surveys are commonly used to collect self-reported data, either on factual information about individuals, or their opinions. They generally have a cross-sectional design and represent a form primary data collection conducted through questionnaires administered by web, phone or paper.

Although used for a long time in other areas as social science or marketing, surveys are nowadays also increasingly used in pharmacoepidemiology, especially in the areas of epidemiology and evaluation of risk minimisation measure (RMM) effectiveness.

Questionnaires used in surveys should be validated based on accepted measures including construct, criterion and content validity, inter-rater and test-retest reliability, sensitivity and responsiveness.

Recommendations with regards to data collection, which medium to use, how to recruit a representative sample and how to formulate the questions in a non-directive way to avoid information bias, are described in the following textbooks: *Survey Sampling* (L. Kish, Wiley, 1995) and *Survey Methodology* (R.M. Groves, F.J. Fowler, M.P. Couper et al., 2nd Edition, Wiley 2009).

Although primarily focused on quality of life research, the book *Quality of Life: the assessment, analysis and interpretation of patient-related outcomes* (P.M. Fayers, D. Machin, 2nd Edition, Wiley, 2007) offers a comprehensive review of the theory and practice of developing, testing and analysing questionnaires in different settings. *Health Measurement Scales: a practical guide to their development and use* (D. L. Streiner, G. R. Norman, 4th Edition, Oxford University Press, 2008) is a very helpful guide to those involved in measuring subjective states and learning style in patients and healthcare providers.

Representativeness is an important element for surveys; the included sample should be representative of the target population and must be defined with regards to the research question. For example, if the objective of the survey is to evaluate whether the RMM are distributed among the right target population, the lists which are used for the distribution of the RMM material cannot be used as the source population for sampling.

The response rate is also an important metric of survey and it should be reported for each survey based on a standard definition so that the comparison among different surveys is possible. [Standard Definitions. Final Dispositions of Case Codes and Outcome Rates for Surveys](#) of the American Association for Public Opinion Research provides standard definitions which can be adapted to the context of pharmacoepidemiological surveys. The overall response rate of participation remains low in telephone surveys (J.M. Lepkowski, N.C. Tucker, J.M Bricket al., Ed. *Advances in telephone survey methodology* Wiley 2007, Part V) and is important to counteract since it leads to lack of power and reduced representativeness. These measures include the use of short or personalised questionnaires approved by professional associations.

4.1.2. Randomised clinical trials

Randomised clinical trials are another form of primary data collection. There are numerous textbooks and publications on methodological and operational aspects of clinical trials and they are not covered here. An essential guideline on clinical trials is the European Medicines Agency (EMA) [Note for Guidance on Good Clinical Practice](#), which specifies obligations for the conduct of clinical trials to ensure that the data generated in the trial are valid.

4.2. Secondary data collection

Secondary data collection refers to collection of data already gathered for another purpose (e.g. electronic healthcare data, claims or prescription data). These can also be linked to non-medical data. The last two decades have witnessed the development of key data resources, expertise and methodology that have allowed use of such data for pharmacoepidemiology. The [ENCePP Inventory of Data Sources](#) contains key information on the databases that are registered in ENCePP. Section 4.6 of this Guide also describes existing research networks.

A comprehensive description of the main features and applications of frequently used databases for pharmacoepidemiology research in the United States and in Europe appears in the book *Pharmacoepidemiology* (B. Strom, S.E. Kimmel, S. Hennessy. 5th Edition, Wiley, 2012, Chapters 11 - 18). The limitations existing in using electronic healthcare databases should be acknowledged, as detailed in [A review of uses of healthcare utilisation databases for epidemiologic research on therapeutics](#) (J Clin Epidemiol 2005; 58: 23-337).

The primary purpose of the ISPE-endorsed [Guidelines for Good Database Selection and use in Pharmacoepidemiology Research](#) (Pharmacoepidemiol Drug Saf 2012;21:1-10) is to assist in the selection and use of data resources in pharmacoepidemiology by highlighting potential limitations and recommending tested procedures. This text mainly refers to databases of routinely collected healthcare information and does not include spontaneous report databases. It is a simple, well-structured guideline that will help investigators when selecting databases for their research and helps database custodians to describe their database in a useful manner. An entire section is dedicated to the use of multi-site studies. The entire document contains references to data quality and data processing/transformation issues and there are sections dedicated to quality and validation procedures. There are also separate sections on privacy and security.

The Working Group for the Survey and Utilisation of Secondary Data (AGENS) with representatives from the German Society for Social Medicine and Prevention (DGSPM) and the German Society for Epidemiology (DGEpi) developed a [Good Practice in Secondary Data Analysis Version 2](#) aiming to establish a standard for planning, conducting and analysing studies on the basis of secondary data. It is also aimed to be used as the basis for contracts between data owners (so-called primary users) and secondary users. It is divided into 11 sections addressing, among other aspects, the study protocol, quality assurance and data protection.

The [FDA's Best Practices for Conducting and Reporting Pharmacoepidemiologic Safety Studies Using Electronic Health Care Data Sets](#) provides criteria for best practice that apply to design, analysis, conduct and documentation. It emphasizes that investigators should understand potential limitations of electronic healthcare data systems, make provisions for their appropriate use and refer to validation studies of safety outcomes of interest in the proposed study and captured in the database.

General guidance for studies including those conducted with electronic healthcare databases can also be found in the [ISPE GPP](#), in particular sections IV-B (Study conduct, Data collection). This guidance emphasises the paramount importance of patient data protection.

The [International Society for Pharmacoeconomics and Outcome Research \(ISPOR\)](#) established a task force to recommend good research practices for designing and analysing retrospective databases for comparative effectiveness research (CER). The Task Force has subsequently published three articles ([Part I](#), [Part II](#) and [Part III](#)) that review methodological issues and possible solutions for CER studies based on secondary data analysis (see also section 10.1 on comparative effectiveness research). Many of the principles are applicable to studies with other objectives than CER, but aspects of pharmacoepidemiological studies based on secondary use of data, such as data quality, ethical issues, data ownership and privacy, are not covered.

Particular issues to be considered in the use of electronic healthcare data for pharmacoepidemiological research include the following:

- Completeness of data capture: does the database reliably capture all of the patient's healthcare interactions or are there known gaps in coverage, capture, longitudinality or eligibility? Researchers using claims data rarely have the opportunity to carry out quality assurance on the whole data set. [Descriptive analyses of the integrity of a US Medicaid Claims Database](#) (Pharmacoepidemiol Drug Saf 2003; 12: 103–11) concludes that performing such analyses can reveal important limitations of the data and whenever possible, researchers should examine the 'parent' data set for apparent irregularities.
- The relevance of bias in assessment of drug exposure for quality control in clinical databases: [European Surveillance of Antimicrobial Consumption \(ESAC\): Data Collection Performance and Methodological Approach](#) (Br J Clin Pharmacol 2004; 58: 419-28) describes a retrospective data collection effort (1997–2001) through an international network of surveillance systems, aimed at collecting publicly available, comparable and reliable data on antibiotic use in Europe. The data collected were screened for bias, using a checklist focusing on detection bias in sample and census data, errors in assigning medicinal product packages to the [Anatomical Therapeutic Chemical Classification System](#), errors in calculations of [Defined Daily Doses](#) per package, bias by over-the-counter sales and parallel trade, and bias in ambulatory/hospital care mix. The authors describe the methodological rigour needed to assure data validity and to ensure reliable cross-national comparison.
- Validity of diagnoses: [Validation and validity of diagnoses in the General Practice Research Database \(GPRD\): a systematic review](#) (Br J Clin Pharmacol 2010; 69: 4-14) investigated the range of methods used to validate diagnoses in a primary care database and concluded that a number of methods had been used to assess validity and that overall, estimates of validity were high. The quality of reporting of the validations was, however, often inadequate to permit a clear interpretation. Not all methods provided a quantitative estimate of validity and most methods considered only the positive predictive value of a set of diagnostic codes in a highly selected group of cases.
- Discordance between data sources: [Discordance of databases designed for claims payment versus clinical information systems: implications for outcomes research](#) (Ann Intern Med 1993; 119: 844-50) is a comparative study of a clinical versus an insurance claims database for predictors of prognosis in patients with ischaemic heart disease. A finding was that claims data failed to identify more than half of the patients with conditions important for prognosis when compared with the clinical information system.
- The impact of changes over time in data, access methodology and the environment: [Evidence generation from healthcare databases: recommendations for managing change](#) (Pharmacoepidemiol Drug Saf 2016; 25(7): 749-754) proposes aspects to be considered to minimise the occurrence of problems of validity, reproducibility and comparability because of changes in the data or systems. A section addresses issues that may occur where common data models and associated tools are introduced.

An example of the hazards of using large linked databases is provided in [Vaccine safety surveillance using large linked databases: opportunities, hazards and proposed guidelines](#) (Expert Rev Vaccines 2003; 2(1): 21-9).

Quality management is further addressed in section 7 of the Guide.

4.3. Patient registries

4.3.1. Definition

A registry is an organised system that uses observational methods to collect uniform data on specified outcomes in a population defined by a particular disease, condition or exposure. A register is the database deriving from the registry (such as the [EU PAS Register](#)), and the difference between the two terms should be clearly understood even if they are often used interchangeably. The terms 'register' or 'registry' are sometimes incorrectly used to designate an exhaustive list of all patients who meet the eligibility criteria of a study, regardless of their inclusion in the study. The term 'patient log-list' could be used for this purpose.

A patient registry should be considered as a structure for the standardised recording of data from routine clinical practice on individual patients identified by the diagnosis of a disease, the occurrence of a condition (e.g., pregnancy), the prescription of a medicinal product (e.g., monoclonal antibodies), a hospital encounter, or any combination of these.

In European Nordic countries where there is a comprehensive registration of hospital data for a high proportion of the population, government-administered patient registries are administrative systems based on hospital encounters including visit information, diagnoses and procedures, such as the [Norwegian Patient Registry](#), the [Danish National Patient Registry](#) or the [Swedish National Patient Register](#). They may however lack information on lifestyle factors, patient-related outcomes and laboratory data. [A review of 103 Swedish Healthcare Quality Registries](#) (J Intern Med 2015; 277(1): 94–136) describes additional healthcare quality registries focusing on specific disorders initiated in Sweden mostly by physicians with data on aspects of disease management, self-reported quality of life, lifestyle, and general health status, providing an important source for research.

4.3.2. Conceptual differences between a registry and a study

As illustrated in [Registries in European post-marketing surveillance: a retrospective analysis of centrally approved products, 2005–2013](#) (Pharmacoepidemiol Drug Saf 2017 Mar 26), the conceptual differences between registries and studies need to be clearly understood.

Patient registries are often integrated into routine clinical practice with systematic and sometimes automated data capture in electronic healthcare records, but disease, exposure or outcome-specific registries usually require recording of specific relevant data. Whilst the duration of a registry is normally open-ended, that of a study is dictated by the time needed to define and collect data relevant for the specific study objectives. Studies also often require introduction of specific procedures, questionnaires or data collection tools. Studies are set up and managed based on limited endpoints and a specific protocol, whereas patient registries are traditionally set up focusing on system(s) specifications in order to ensure a continuous, efficient and collaborative data collection; safe data hosting; accessible, retrievable, interoperable and re-usable data.

A registry can be used as a source of patients for studies based on either primary data collection (where the data collected for new patients are also used for a specific study) or secondary data collection (analogously to the use of electronic healthcare records). For this purpose, registries data can be enriched with additional information on outcomes, lifestyle data, immunisation and mortality information obtained from linkage to the existing database such as national cancer registries, prescription databases or mortality records.

4.3.3. Methodological guidance

The US Agency for Health Care Research and Quality (AHRQ) published a comprehensive document on 'good registry practices' entitled [Registries for Evaluating Patient Outcomes: A User's Guide](#), 3rd Edition, which provides methodological guidance on planning, design, implementation, analysis, interpretation and evaluation of the quality of a registry. There is a dedicated section for linkage of registries to other data sources. The EU [PARENT Joint Action](#) developed methodological and governance guidelines to facilitate cross-border use of registries.

Results obtained from analyses of registry data may be affected by the same biases as those of studies described in section 5.2 Bias and confounding. Registries are particularly sensitive to the occurrence of selection bias. This is due to the fact that factors that may influence the enlistment of patients in a registry may be numerous (including clinical, demographic and socio-economic factors) and difficult to predict and identify, potentially resulting in a biased sample of the patient population in case the recruitment has not been exhaustive. In addition, studies that use registry data may also introduce selection bias in the recruitment or selection of registered patient for the specific study, as well as in the differential completeness of follow-up and data collection. It is therefore important to systematically compare the characteristics of the study population with those of the source population.

The randomised registry trial is a new study design that combines the robustness of randomised studies with the higher generalisability of registry data, see section 5.6.3.

4.3.4. Registries which capture special populations

In assessing both safety and effectiveness, special populations can be identified based on age (e.g., paediatric or elderly), pregnancy status, renal or hepatic function, race, or genetic differences. Some registries are focused on these particular populations. Examples of these are the birth registries in Nordic countries.

The [FDA's Guidance for Industry-Establishing Pregnancy Exposure Registries](#) advises on good practice for designing a pregnancy registry with a description of research methods and elements to be addressed. The [Systematic overview of data sources for drug safety in pregnancy research](#) provides an inventory of pregnancy exposure registries and alternative data sources on safety of prenatal drug exposure and discusses their strengths and limitations. Example of population-based registers allowing to assess outcome of drug exposure during pregnancy are [EUROCAT](#), the European network of registries for the epidemiologic surveillance of congenital anomalies, and the pan-Nordic registries which record drug use during pregnancy as illustrated in [Selective serotonin reuptake inhibitors and venlafaxine in early pregnancy and risk of birth defects: population based cohort study and sibling design](#) (BMJ 2015; 350: h1798).

For paediatric populations, detailed information on neonatal age (e.g. in days, not just in years), pharmacokinetic differences and organ maturation need to be considered. The [CHMP Guideline on Conduct of Pharmacovigilance for Medicines Used by the Paediatric Population](#) provides further relevant information. An example of registry which focuses on paediatric patients is [Pharmachild](#), which captures children with juvenile idiopathic arthritis undergoing treatment with methotrexate or biologic agents.

Other registries that focus on special populations (e.g., the [UK Renal Registry](#)) can be found in the [ENCePP Inventory of data sources](#).

4.3.5. Disease registries in regulatory practice and health technology assessment

Annex 1 of [Module VIII](#) of the Good pharmacovigilance practice provides guidance on use of patient registries for regulatory purpose. It emphasises that the choice of the registry population and the design of the registry should be driven by its objective(s) in terms of outcomes to be measured and analyses and comparisons to be performed. As existing disease registries gather insights into the natural history and clinical aspects of diseases and allow comparison of outcomes between different treatments prescribed for the same indication, they are generally preferred to product registries for regulatory purposes. Module VIII also acknowledges that, due to their observational nature, registries should not normally be used to demonstrate effectiveness in real world setting, although in some cases (such as rare disease, rare exposure or special population), registries may be the only opportunity to provide insight into effectiveness aspects of a medicinal product. On the other hand, even when efficacy has been demonstrated in randomized clinical trials (RCTs), registries may be useful to study effectiveness in heterogeneous populations and effect modifiers, such as doses that have been prescribed by physicians and that may differ from those used in RCTs, patient sub-groups defined by variables such as age, co-morbidities, use of concomitant medication or genetic factors, or factors related to a defined country or healthcare system that might influence effectiveness.

To support better use of existing registries and facilitate the establishment of high-quality new registries, the EU regulatory network developed the Patient registries initiative. As part of this initiative, the ENCePP Resource database of data sources was used to support an inventory of existing disease registries.

Incorporating data from clinical practice into the drug development process is a growing interest from health technology assessment (HTA) bodies and payers since reimbursement decisions can benefit from better estimation and prediction of effectiveness of treatments at the time of product launch. An example of where registries can provide clinical practice data is to support the building of predictive models that incorporate data from both RCTs and registries to bridge the efficacy-effectiveness gap, i.e. to generalise results observed in RCTs to a real-world setting. Collecting relevant HTA data in early development and planning post-authorisation data collection may therefore support rapid relative effectiveness assessment and decision-making on drug pricing and reimbursement. In this context, the [EUnetHTA Joint Action 3 project](#) has issued guidelines for the definition of the research questions and the choice of data sources and methodology that will support the generation of post-launch evidence.

4.4. Spontaneous report database

Spontaneous reports of adverse drug effects remain a cornerstone of pharmacovigilance and are collected from a variety of sources, including healthcare providers, national authorities, pharmaceutical companies, medical literature and more recently directly from patients. [EudraVigilance](#) is the European Union data processing network and management system for reporting and evaluation of suspected adverse drug reactions (ADRs). [The Global Individual Case Safety Reports Database System \(VigiBase\)](#) pools reports of suspected ADRs from the members of the WHO programme for international drug monitoring. These systems deal with the electronic exchange of Individual Case Safety Reports (ICSRs), the early detection of possible safety signals and the continuous monitoring and evaluation of potential safety issues in relation to reported ADRs. The report [Characterization of databases \(DB\) used for signal detection \(SD\)](#) of the PROTECT project shows the heterogeneity of spontaneous databases and the lack of comparability of SD methods employed. This heterogeneity is an important consideration when assessing the performance of SD algorithms.

The strength of spontaneous reporting systems is that they cover all types of legal drugs used in any setting. In addition to this, the reporting systems are built to obtain information specifically on potential adverse drug reactions and the data collection concentrates on variables relevant to this objective and directs reporters towards careful coding and communication of all aspects of an ADR. The increase in systematic collection of ICSRs in large electronic databases has allowed the application of data mining and statistical techniques for the detection of safety signals. There are known limitations of spontaneous ADR reporting systems, which include limitations embedded in the concept of voluntary reporting, whereby known or unknown external factors may influence the reporting rate and data quality. ICSRs may be limited in their utility by a lack of data for an accurate quantification of the frequency of events or the identification of possible risk factors for their occurrence. For these reasons, the concept is now well accepted that any signal from spontaneous reports needs to be verified clinically before further communication.

One challenge in spontaneous report databases is report duplication. Duplicates are separate and unlinked records that refer to one and the same case of a suspected ADR and may mislead clinical assessment or distort statistical screening. They are generally detected by individual case review of all reports or by computerised duplicate detection algorithms. In [Performance of probabilistic method to detect duplicate individual case safety reports](#) (Drug Saf 2014; 37(4): 249-58) a probabilistic method highlighted duplicates that had been missed by a rule-based method and also improved the accuracy of manual review. In the study, however, a demonstration of the performance of de-duplication methods to improve signal detection is lacking.

[Validation of statistical signal detection procedures in EudraVigilance post-authorisation data: a retrospective evaluation of the potential for earlier signalling](#) (Drug Saf 2010; 33: 475 – 87) has shown that the statistical methods applied in EudraVigilance can provide significantly early warning in a large proportion of drug safety problems. Nonetheless, this approach should supplement, rather than replace, other pharmacovigilance methods.

Chapters IV and V of the [Report of the CIOMS Working Group VIII 'Practical aspects of Signal detection in Pharmacovigilance'](#) present sources and limitations of spontaneously-reported drug-safety information and databases that support signal detection. Appendix 3 of the report provides a list of international and national spontaneous reporting system database.

4.5. Social media and electronic devices

Technological advances have dramatically increased the range of data sources that can be used to complement traditional ones and provide compelling insights into effectiveness and safety of interventions. Such data include digital social media that exist in a computer-readable format on websites, web pages, blogs, vlogs, social networking sites, internet forums, chat rooms, health portals, etc. A recent addition to this list is represented by the data collected through mobile and other device applications such as wearable technology.

There is a growing interest to use these data sources to generate patient-generated information relevant for medicines safety surveillance.

Social media is a source of potential reports of suspected ADRs. Marketing authorisation holders (MAHs) are legally obliged to screen web sites under their management and assess whether they qualify for reporting. Spontaneous ADRs identified from social media should be handled as unsolicited reports and evaluated and reported in a similar way.

Social media is already being used to provide insights into the patient's perception of the effectiveness of drugs and for the collection of patient reported outcomes (PROs) as discussed in [Web-based patient-reported outcomes in drug safety and risk management: challenges and opportunities?](#) (Drug Saf. 2012; 35(6): 437-46).

Another use of social media might be for identification of new safety issues (signal detection). It would have added value only if more issues would be identified or it would help faster identification, but there is currently no evidence this is the case. [Using Social Media Data in Routine Pharmacovigilance: A Pilot Study to Identify Safety Signals and Patient Perspectives](#) (Pharm Med (2017) 31: 167-174) explores whether analysis of social media data could identify new signals, known signals from routine pharmacovigilance, known signals sooner, and specific issues (*i.e.*, quality issues and patient perspectives). Also of interest in this study was to determine the quantity of 'posts with resemblance to AEs' (proto-AEs) and the types and characteristics of products that would benefit from social media analysis. It concludes that social media data analysis cannot identify new safety signals but can provide unique insight into the patient perspective. Assessment was limited by numerous factors, such as data acquisition, language, and demographics. Further research is deemed necessary to determine the best uses of social media data to augment traditional pharmacovigilance surveillance.

There is one ongoing EU project investigating the potential for publicly available social media data for identifying drug safety issues ([WEB-RADR](#)). The results of the WEB-RADR project will inform regulatory policy on the use of social media for pharmacovigilance, initial results show there may be utility for specific niche areas such as misuse/abuse or off-label use.

While offering the promise of new research models and approaches, the rapidly evolving social media environment presents many challenges including the need for strong and systematic processes for selection, validation and study implementation. Articles which detail associated challenges are: [Evaluating Social Media Networks in Medicines Safety Surveillance: Two Case Studies](#) (Drug Saf. 2015; 38(10): 921–930.) and [Social media and pharmacovigilance: A review of the opportunities and challenges](#) (Br J Clin Pharmacol. 2015 Oct; 80(4): 910–920).

There is currently no defined strategy or framework in place in order to meet the standards around data validity, generalisability for this type of data. Therefore regulatory acceptance of this type of data might be lower than for traditional sources.

More tools and solutions for analysing unstructured data, especially for pharmacoepidemiology and drug safety research, are becoming available, as in [Deep learning for pharmacovigilance: recurrent neural network architectures for labelling adverse drug reactions in Twitter posts](#) (J Am Med Inform Assoc. 2017 Feb 22) and [Social Media Listening for Routine Post-Marketing Safety Surveillance](#) (Drug Saf. 2016;39(5):443-54).

Before an informed strategy is put in place, the following factors may be considered when using social media and electronic data sources and devices using social media:

- Completeness of data capture.
- Validation processes defined for the devices, including accuracy
- Reliability and reproducibility of outputs/inputs from the device
- Data warehousing requirements for secure storage of the volume of data potentially received from wearable devices.

Data from social media and electronic devices can be both structured and unstructured. When analysing unstructured data, the following factors may be considered:

- Tools used for crawling the web and the methods used for handling unstructured data should be well defined along with their potential limitations e.g. the type of natural language processing (NLP) approach and software used.
- How exposure and outcomes were defined within unstructured data and whether these have been derived and validated.

4.6. Research networks

4.6.1. General considerations

The need to pool data across different databases in order to gain power and increase generalisability of the results is becoming increasingly necessary. In Europe, collaborations for multi-database studies have been strongly encouraged over the last years by the drug safety research funded by the European Commission (EC) and public-private partnerships such as the Innovative Medicines Initiative (IMI). The funding resulted in the conduct of groundwork necessary to overcome the hurdles of data sharing across countries. A growing number of studies use data from networks of databases, often from different countries.

In the US, [the HMO Research Network \(HMORN\)](#), the [OHDSI](#) and the [Sentinel initiative](#) are examples of consortia involving health maintenance organisations that have formal, recognised research capabilities. Networking implies collaboration between investigators in sharing expertise and resources. The [ENCePP Database of Research Resources](#) may facilitate such networking by providing an inventory of research centres and data sources that can collaborate on specific pharmacoepidemiology and pharmacovigilance studies in Europe. It allows the identification of centres and data sets by country, type of research and other relevant fields.

From a methodological point of view, research networks have many advantages:

- The potential for pooling data or results maximises the amount of information gathered for a specific issue addressed in different databases.
- Research networks increase the size of study populations and shorten the time needed for obtaining the desired sample size. Hence, they can facilitate research on rare events and speed-up investigation of drug safety issues.
- The heterogeneity of treatment options across countries allows studying the effect of individual drugs.
- Research networks may provide additional knowledge on whether a drug safety issue exists in several countries and thereby reveal causes of differential drug effects, on the generalisability of results, on the consistency of information and on the impact of biases on estimates.
- Involvement of experts from various countries addressing case definitions, terminologies, coding in databases and research practices provides opportunities to increase consistency of results of observational studies.
- Sharing of data sources facilitates harmonisation of data elaboration and transparency in analyses and benchmarking of data management.

Different models have been applied for combining data or results from multiple databases. A common characteristic of all models is the fact that data partners maintain physical and operational control over electronic data in their existing environment. Differences however exist on whether a common protocol or a common data model is applied across all databases to extract, analyse and combine the data. A common data model (CDM) approach provides a similar representation of the database that allows standardisation of administrative and clinical information and facilitates a combined analysis across several databases. The CDM can be systematically applied on all data of a database (generalised CDM) or on the subset of data needed for a specific study (study-specific CDM).

4.6.2. Models of studies using multiple data sources

i) Local data extraction and analysis, separate protocols

The traditional way to combine data from multiple data sources is when data extraction and analysis are performed independently at each centre based on separate protocols. This is usually followed by meta-analysis of the different estimates obtained (see Chapter 5.7).

ii) Local data extraction and analysis, common protocol

In this option, data are extracted and analysed locally on the basis of a common protocol. Definitions of exposure, outcomes and covariates, analytical programmes and reporting formats are standardised according to a common protocol and the results of each analysis are shared in an aggregated format and pooled together through meta-analysis. This approach allows assessment of database/population characteristics and their impact on estimates but reduces variability of results determined by differences in design. Examples of research networks that use the common protocol approach are the [PROTECT project](#) (as described in [Improving Consistency and Understanding of Discrepancies of Findings from Pharmacoepidemiological Studies: the IMI PROTECT Project](#). (Pharmacoepidemiol Drug Saf 2016; 25(S1): 1–165) and [the Canadian Network for Observational Drug Effect Studies \(CNODES\)](#).

This approach requires very detailed common protocols and data specifications that reduce variability in interpretations by researchers.

[Multi-centre, multi-database studies with common protocols: lessons learnt from the IMI PROTECT project](#) (Pharmacoepidemiol Drug Saf 2016; 25(S1): 156-165) states that a priori pooling of data from several databases may disguise heterogeneity that may provide useful information on the safety issue under investigation. On the other hand, parallel analysis of databases allows exploring reasons for heterogeneity through extensive sensitivity analyses. This approach eventually increases consistency in findings from observational drug effect studies or reveal causes of differential drug effects.

iii) Local data extraction and central analysis, common protocol

For some studies, it has been possible to analyse centrally patient level data extracted based on a common protocol, such as in [Selective serotonin reuptake inhibitors during pregnancy and risk of persistent pulmonary hypertension in the newborn: population based cohort study from the five Nordic Countries](#) (BMJ 2012; 344:d8012). If databases are very similar in structure and content as is the case for some Nordic registries, a CDM might not be required for data extraction. The central analysis allows removing an additional source of variability linked to the statistical programming and analysis.

iv) Local data extraction and central analysis, study-specific common data model

Data can also be extracted from local databases using a study-specific, database-tailored extraction into a CDM and pre-processed locally. The resulting data can be transmitted to a central data warehouse as patient-level data or aggregated data for further analysis. Examples of research networks that used this approach by employing a study-specific CDM with transmission of anonymised patient-level data (allowing a detailed characterisation of each database) are [EU-ADR](#) (as explained in [Combining electronic healthcare databases in Europe to allow for large-scale drug safety monitoring: the EU-ADR Project](#), Pharmacoepidemiol Drug Saf 2011; 20(1): 1-11), [SOS](#), [ARITMO](#), [SAFEGUARD](#), [GRIP](#) and [ADVANCE](#).

An approach to expedite the analysis of heterogeneity, called the *component strategy*, was initially developed in the [EMIF project](#) and could also be compatible with the generalised common data model (see [Identifying Cases of Type 2 Diabetes in Heterogeneous Data Sources: Strategy from the EMIF Project](#). PLoS ONE. 2016; 11(8):e0160648).

v) Local data extraction and central analysis, generalised common data model

Two examples of research networks which use a generalised CDM are the [Sentinel Initiative](#) (as described in [The U.S. Food and Drug Administration's Mini-Sentinel Program](#), *Pharmacoepidemiol Drug Saf* 2012;21(S1):1–303) and [OHDSI](#). The main advantage of a general CDM is that it can be used for virtually any study involving the database. OhDSI is based on the Observational Medical Outcomes Partnership (OMOP) CDM which is used by many organisations and has been tested for its suitability for safety studies (see for example [Validation of a common data model for active safety surveillance research](#). *J Am Med Inform Assoc.* 2012;19(1):54–60). OMOP also developed an open source repository for the analytical tools created within the project.

In [A Comparative Assessment of Observational Medical Outcomes Partnership and Mini-Sentinel Common Data Models and Analytics: Implications for Active Drug Safety Surveillance](#) (*Drug Saf.* 2015;38(8):749-65), it is suggested that slight conceptual differences between the Sentinel and the OMOP models do not significant impact on identifying known safety associations. Differences in risk estimations can be primarily attributed to the choices and implementation of the analytic approach.

4.6.3. Challenges of different models

The different models presented above present many challenges:

Related to the scientific content

- Differences in the underlying health care systems and mechanisms of data generation and collection
- Mapping of differing disease coding systems (e.g., the International Classification of Disease, 10th Revision (ICD-10), Read codes, the International Classification of Primary Care (ICPC-2)) and narrative medical information in different languages.
- Validation of study variables and access to source documents for validation.

Related to the organisation of the network

- Differences in culture and experience between academia, public institutions and private partners.
- Differences in the type and quality of information contained within each mapped database.
- Different ethical and governance requirements in each country regarding processing of anonymised or pseudo-anonymised healthcare data.
- Choice of data sharing model and access rights of partners.
- Issues linked to intellectual property and authorship.
- Sustainability and funding mechanisms.

Each model has strengths and weaknesses in facing the above challenges ([Data Extraction and Management in Networks of Observational Health Care Databases for Scientific Research: A Comparison of EU-ADR, OMOP, Mini-Sentinel and MATRICE Strategies](#) (EGEMS. 2016 Feb)). Experience has shown that many of these difficulties can be overcome by full involvement and good communication between partners, and a project agreement between network members defining roles and responsibilities and addressing issues of intellectual property and authorship.

5. Study design and methods

5.1. Definition and validation of drug exposure, outcomes and covariates

Historically, pharmacoepidemiology studies relied on patient-supplied information or searches through paper-based health records. This reliance has been reduced with the rapid expansion of access to electronic healthcare records and existence of large administrative databases. Nevertheless, these data sources have led to variation in the way exposures and outcomes are defined and measured, each requiring validation. Chapter 41 of *Pharmacoepidemiology* (B. Strom, S.E. Kimmel, S. Hennessy. 5th Edition, Wiley, 2012) includes a literature review of the studies that have evaluated the validity of drug, diagnosis and hospitalisation data and the factors that influence the accuracy of these data. The book presents information on primary data sources available for pharmacoepidemiology studies including questionnaires and administrative databases. Further information on databases available for pharmacoepidemiology studies is available in resources such as the [ENCePP resource database](#) and the [Inventory of Drug Consumption Databases in Europe](#).

5.1.1. Assessment of exposure

In pharmacoepidemiology studies, exposure data originate mainly from four sources: data on prescribing (e.g. CPRD primary care data), data on dispensing (e.g. PHARMO outpatient pharmacy database), data on payment for medication (namely claims data, e.g. IMS LifeLink PharMetrics Plus) or from data collected from surveys. The population included in these data sources follows a process of attrition: drugs that are prescribed are not necessarily dispensed, and drugs that are dispensed are not necessarily ingested. In [Primary non-adherence in general practice: a Danish register study](#) (Eur J Clin Pharmacol 2014; 70(6): 757–63), 9.3% of all prescriptions for new therapies were never redeemed at the pharmacy, although with some differences between therapeutic and patient groups. The attrition from dispensing to ingestion is even more difficult to measure, as it involves uncertainties about what dispensed drugs are actually taken by the patients and about the patients' ability to account accurately for their intake. In particular, paediatric adherence is additionally dependent on parents.

Exposure definitions can include simple dichotomous variables (e.g. ever exposed vs. never exposed) or they can be more detailed, including estimates of exposure windows (e.g. current vs. past exposure) or levels of exposure (e.g. current dosage, cumulative dosage over time). Consideration should be given to the level of detail available from the data sources on the timing of exposure, including the quantity prescribed, dispensed or ingested and the capture of dosage instructions when evaluating the feasibility of constructing such variables. This will vary across data sources and exposures (e.g. estimating contraceptive pill ingestion is typically easier than estimating rescue medication for asthma attacks). Discussions with clinicians regarding sensible assumptions will inform variable definition.

The Methodology chapter of the book *Drug Utilization Research. Methods and Applications* (M. Elseviers, B. Wettermark, A.B. Almarsdottir et al. Ed. Wiley Blackwell, 2016) discusses different methods for data collection on drug utilisation.

5.1.2. Assessment of outcomes

A case definition compatible with the observational database should be developed for each outcome of a study at the design stage. This description should include how events will be identified and classified as cases, whether cases will include prevalent as well as incident cases, exacerbations

and second episodes (as differentiated from repeat codes) and all other inclusion or exclusion criteria. The reason for the data collection and the nature of the healthcare system that generated the data should also be described as they can impact on the quality of the available information and the presence of potential biases. Published case definitions of outcomes, such as those developed by the [Brighton Collaboration](#) in the context of vaccinations, are not necessarily compatible with the information available in a given observational data set. For example, information on the duration of symptoms may not be available, or additional codes may have been added to the data set following publication of the outcome definition.

Search criteria to identify outcomes should be defined and the list of codes should be provided. Generation of code lists requires expertise in both the coding system and the disease area. Researchers should also consult clinicians who are familiar with the coding practice within the studied field. Suggested methodologies are available for some coding systems (see [Creating medical and drug code lists to identify cases in primary care databases](#). *Pharmacoepidemiol Drug Saf* 2009; 18(8): 704-7). Coding systems used in some commonly used databases are updated regularly so sustainability issues in prospective studies should be addressed at the protocol stage. Moreover, great care should be given when re-using a code list from another study as code lists depend on the study objective and methods. Public repository of codes as [Clinicalcodes.org](#) is available and researchers are also encouraged to make their own set of coding available.

In some circumstances, chart review or text entries in electronic format linked to coded entries can be useful for outcome identification. Such identification may involve an algorithm with use of multiple code lists (for example disease plus therapy codes) or an endpoint committee to adjudicate available information against a case definition. In some cases, initial plausibility checks or subsequent medical chart review will be necessary. When databases have prescription data only, drug exposure may be used as a proxy for an outcome, or linkage to different databases is required.

5.1.3. Assessment of covariates

In pharmacoepidemiology studies, covariates are often used for selecting and matching study subjects, comparing characteristics of the cohorts, developing propensity scores, creating stratification variables, evaluating effect modifiers and adjusting for confounders. Reliable assessment of covariates is therefore essential for the validity of results. Patient characteristics and other key covariates that could be confounding variables need to be evaluated using all available data. A given database may or may not be suitable for studying a research question depending on the availability of these covariates.

Some patient characteristics and covariates vary with time and accurate assessment is time dependent. The timing of assessment of the covariates is an important factor for the correct classification of the subjects and should be clearly specified in the protocol. Assessment of covariates can be done using different periods of time (look-back periods or run-in periods).

Fixed look-back periods (for example 6 months or 1 year) are sometimes used when there are changes in coding methods or in practices or when it is not feasible to use the entire medical history of a patient. [Estimation using all available covariates information versus a fixed look-back window for dichotomous covariates](#) (*Pharmacoepidemiol Drug Saf.* 2013; 22(5):542-50) establishes that defining covariates based on all available historical data, rather than on data observed over a commonly shared fixed historical window will result in estimates with less bias. However, this approach may not be applicable when data from paediatric and adult periods are combined because covariates may significantly differ between paediatric and adult populations (e.g., height and weight).

5.1.4. Validation

In healthcare databases, the correct assessment of drug exposure, outcome and covariate is crucial to the validity of research. The validation of electronic information on drug exposure, outcome or covariate is crucial for database studies and definitions should be included in the technical handbook of every database, ideally providing estimates of sensitivity, specificity, and the positive and negative predictive value. [Validity of diagnostic coding within the General Practice Research Database: a systematic review](#) (Br J Gen Pract 2010;60:e128-36), the book *Pharmacoepidemiology* (B. Strom, S.E. Kimmel, S. Hennessy. 5th Edition, Wiley, 2012) and [Mini-Sentinel's systematic reviews of validated methods for identifying health outcomes using administrative and claims data: methods and lessons learned](#) (Pharmacoepidemiol Drug Saf. 2012 Jan;21 Suppl 1:82-9) contain examples.

Completeness and validity of all variables used as exposure, outcomes, potential confounders and effect modifiers should be considered. Assumptions included in case definitions or other algorithms may need to be confirmed. For databases routinely used in research, documented validation of key variables may have been done previously by the data provider or other researchers. Any extrapolation of previous validation should, however, consider the effect of any differences in variables or analyses and subsequent changes to health care, procedures and coding. A full understanding of both the health care system and procedures that generated the data is required. This is particularly important for studies relying upon accurate timing of exposure, outcome and covariate recording such as in the self-controlled case series. External validation against chart review or physician/patient questionnaire is possible with some resources. However, the questionnaires cannot always be considered as 'gold standard'.

Review of records against a case definition by experts may also be possible. While false positives are more easily measured than false negatives, specificity of an outcome is more important than sensitivity when considering bias in relative risk estimates (see [A review of uses of health care utilization databases for epidemiologic research on therapeutics](#). J Clin Epidemiol 2005;58(4):323-37). Alternatively, internal logic checks can test for completeness and accuracy of variables. For example, one can investigate whether an outcome was followed by (or preceded from) appropriate exposure or procedures.

Concordance between datasets such as comparison of cancer or death registries with clinical or administrative records can validate individual records or overall incidence or prevalence rates. Linkage validation can be used as well, when another database is used for the validation of current one, through linkage methods ([Using linked electronic data to validate algorithms for health outcomes in administrative databases](#). J Comp Eff Res. 2015 Aug;4(4):359-66.)

5.2. Bias and confounding

5.2.1. Selection bias

Selection bias entails the selective recruitment into the study of subjects that are not representative of the exposure or outcome pattern in the source population. Examples of selection bias are referral bias, self-selection bias, prevalence bias or protopathic bias (Strom BL, Kimmel SE, Hennessy S. *Pharmacoepidemiology*, 5th Edition, Wiley, 2012).

Protopathic bias

Protopathic bias arises when the initiation of a drug (exposure) occurs in response to a symptom of the (at this point undiagnosed) disease under study (outcome). For example, use of analgesics in response to pain caused by an undiagnosed tumour might lead to the erroneous conclusion that

the analgesic caused the tumour. Protopathic bias thus reflects a reversal of cause and effect ([Bias: Considerations for research practice](#). Am J Health Syst Pharm 2008; 65:2159-68). This is particularly a problem in studies of drug-cancer associations and other outcomes with long latencies. It may be handled by including a time-lag, i.e. by disregarding all exposure during a specified period of time before the index date.

Prevalence bias

The practice of including prevalent users in observational studies, i.e. patients taking a therapy for some time before study follow-up began, can cause two types of bias. Firstly, prevalent users are 'survivors' (healthy-users) of the early period of pharmacotherapy, which can introduce substantial selection bias if risk varies with time, as seen in the association between contraceptive intake and venous thrombosis which was initially overestimated due to the healthy-users bias. ([The Transnational Study on Oral Contraceptives and the Health of Young Women. Methods, results, new analyses and the healthy user effect](#), Hum Reprod Update. 1999 Nov-Dec;5(6)). Secondly, covariates for drug users at study entry are often plausibly affected by the drug itself.

5.2.2. Information bias

Information bias arises when incorrect information about either exposure or outcome or any covariates is collected in the study. It can be either non-differential when it does occur randomly across exposed/non-exposed participants or differential when it is influenced by the disease or exposure status.

Non differential misclassification bias drives the risk estimate towards the null value, while differential bias can drive the risk estimate in either direction. Examples of non-differential misclassification bias are recall bias (e.g., in case controls studies cases and controls can have different recall of their past exposures) and surveillance or detection bias.

Surveillance bias (or detection bias)

Surveillance or detection bias arises when patients in one exposure group have a higher probability of having the study outcome detected, due to increased surveillance, screening or testing of the outcome itself, or an associated symptom. For example, post-menopausal exposure to estrogen is associated with an increased risk of bleeding that can trigger screening for endometrial cancers, leading to a higher probability of early stage endometrial cancers being detected. Any association between estrogen exposure and endometrial cancer potentially overestimates risk, because unexposed patients with sub-clinical cancers would have a lower probability of their cancer being diagnosed or recorded. This is discussed in [Alternative analytic methods for case-control studies of estrogens and endometrial cancer](#) (N Engl J Med 1978; 299(20):1089-94).

This non-random type of misclassification bias can be reduced by selecting an unexposed comparator group with a similar likelihood of screening or testing, selecting outcomes that are likely to be diagnosed equally in both exposure groups, or by adjusting for the surveillance rate in the analysis. The issues and recommendations are outlined in [Surveillance Bias in Outcomes Reporting](#) (JAMA, 2011; 305(23):2462-3).

Time-related bias

Time-related bias is most often a form of differential misclassification bias and is triggered by inappropriate accounting of follow-up time and exposure status in the study design and analysis.

The choice of the exposure risk window can influence risk comparisons due to misclassification of drug exposure possibly associated with risks that vary over time. [A study of the effects of exposure misclassification due to the time-window design in pharmacoepidemiologic studies](#) (Clin Epidemiol

1994;47(2):183–89) considers the impact of the time-window design on the validity of risk estimates in record linkage studies. In adverse drug reaction studies, an exposure risk-window constitutes the number of exposure days assigned to each prescription. The ideal design situation would occur when each exposure risk-window would only cover the period of potential excess risk. The estimation of the time of drug-related risk is however complex as it depends on the duration of drug use, timing of ingestion and the onset and persistence of drug toxicity. With longer windows, a substantive attenuation of incidence rates may be observed. Risk windows should be validated or sensitivity analyses should be conducted.

Immortal time bias

Immortal time bias refers to a period of cohort follow-up time during which death (or an outcome that determines end of follow-up) cannot occur. (K. Rothman, S. Greenland, T. Lash. *Pharmacoepidemiology*, 3rd Edition, Lippincott Williams & Wilkins, 2008 p. 106-7).

Immortal time bias can arise when the period between cohort entry and date of first exposure to a drug, during which the event of interest has not occurred, is either misclassified or simply excluded and not accounted for in the analysis. [Immortal time bias in observational studies of drug effects](#) (*Pharmacoepidemiol Drug Saf* 2007; 16: 241-9) demonstrates how several observational studies used a flawed approach to design and data analysis, leading to immortal time bias, which can generate an illusion of treatment effectiveness. This is frequently found in studies that compare groups of 'users' against 'non-users'. Observational studies with surprisingly beneficial drug effects should therefore be re-assessed to account for this bias.

[Immortal time bias in Pharmacoepidemiology](#) (*Am J Epidemiol* 2008; 167:492-9) describes various cohort study designs leading to this bias, quantifies its magnitude under different survival distributions and illustrates it with data from a cohort of lung cancer patients. For time-based, event-based and exposure-based cohort definitions, the bias in the rate ratio resulting from misclassified or excluded immortal time increases proportionately to the duration of immortal time.

[Survival bias associated with time-to-treatment initiation in drug effectiveness evaluation: a comparison of methods](#) (*Am J Epidemiol* 2005; 162: 1016-23) describes five different approaches to deal with immortal time bias. The use of a time-dependent approach had several advantages: no subjects were excluded from the analysis and the study allowed effect estimation at any point in time after discharge. However, changes of exposure might be predictive of the study endpoint and need adjustment for time-varying confounders using complex methods. [Problem of immortal time bias in cohort studies: example using statins for preventing progression of diabetes](#) (*BMJ* 2010; 340:b5087) describes how immortal time in observation studies can bias the results in favour of the treatment group and how they can be identified and avoided. It is recommended that all cohort studies should be assessed for the presence of immortal time bias using appropriate validity criteria. However, [Re. 'Immortal time bias on pharmacoepidemiology'](#) (*Am J Epidemiol* 2009; 170: 667-8) argues that sound efforts at minimising the influence of more common biases should not be sacrificed to that of avoiding immortal time bias.

Other forms of time-related bias

[Time-window Bias in Case-control Studies. Statins and Lung Cancer](#) (*Epidemiology* 2011; 22 (2):228-31) describes a case-control study which reported a 45% reduction in the rate of lung cancer with any statin use. A differential misclassification bias arose from the methods used to select controls and measure their exposure, which resulted in exposure assessment to statins being based on a shorter time-span for cases than controls and an over-representation of unexposed cases. Properly accounting for time produced a null association.

In many database studies, exposure status during hospitalisations is unknown. Exposure misclassification bias may occur with a direction depending on whether exposure to drugs

prescribed preceding hospitalisations are continued or discontinued and if days of hospitalisation are considered as gaps of exposure or not, especially during hospitalisation when several exposure categories are assigned, such as current, recent and past. The differential bias arising from the lack of information on (or lack of consideration of) hospitalisations that occur during the observation period (called 'immeasurable time bias' described in [Immeasurable time bias in observational studies of drug effects on mortality](#). Am J Epidemiol 2008;168 (3):329-35) can be particularly problematic when studying serious chronic diseases that require extensive medication use and multiple hospitalisations.

In the case of case control studies assessing chronic diseases with multiple hospitalizations and in-patient treatment (such as the use of inhaled corticosteroids and death in chronic obstructive pulmonary disease patients), no clearly valid approach to data analysis can fully circumvent this bias. However, sensitivity analyses such as restricting the analysis to non-hospitalised patients or providing estimates weighted by exposable time may provide additional information on the potential impact of this bias: [Immeasurable time bias in observational studies of drug effects on mortality](#). (Am J Epidemiol 2008;168 (3):329-35).

In cohort studies where a first-line therapy (such as metformin) has been compared with second- or third-line therapies, patients are unlikely to be at the same stage of the disease (e.g. diabetes), which can induce confounding of the association with an outcome (e.g. cancer incidence) by disease duration. An outcome related to the first-line therapy may also be attributed to the second-line therapy if it occurs after a long period of exposure. Such situation requires matching on disease duration and consideration of latency time windows in the analysis (example drawn from [Metformin and the Risk of Cancer. Time-related biases in observational studies](#). Diabetes Care 2012;35(12):2665-73).

5.2.3. Confounding

Confounding occurs when the estimate of measure of association is distorted by the presence of another risk factor. For a variable to be a confounder, it must be associated with both the exposure and the outcome, without being in the causal pathway.

Confounding by indication

Confounding by indication refers to a determinant of the outcome parameter that is present in people at perceived high risk or poor prognosis and is an indication for intervention. This means that differences in care, for example, between cases and controls may partly originate from differences in indication for medical intervention such as the presence of risk factors for particular health problems. Other names for this type of confounding are 'channelling' or 'confounding by severity'.

This type of confounding has frequently been reported in studies evaluating the efficacy of pharmaceutical interventions and is almost always encountered in various extents in pharmacoepidemiological studies. A good example can be found in [Confounding and indication for treatment in evaluation of drug treatment for hypertension](#) (BMJ 1997;315:1151-4).

The article [Confounding by indication: the case of the calcium channel blockers](#) (Pharmacoepidemiol Drug Saf 2000;9:37-41) demonstrates that studies with potential confounding by indication can benefit from appropriate analytic methods, including separating the effects of a drug taken at different times, sensitivity analysis for unmeasured confounders, instrumental variables and G-estimation.

With the more recent application of pharmacoepidemiological methods to assess effectiveness, confounding by indication is a greater challenge and the article [Approaches to combat with](#)

[confounding by indication in observational studies of intended drug effects](#) (Pharmacoepidemiol Drug Saf 2003;12:551-8) focusses on its possible reduction in studies of intended effects. An extensive review of these and other methodological approaches discussing their strengths and limitations is discussed in [Methods to assess intended effects of drug treatment in observational studies are reviewed](#) (J Clin Epidemiol 2004;57:1223-31).

Unmeasured confounding

Complete adjustment for confounders would require detailed information on clinical parameters, lifestyle or over-the-counter medications, which are often not measured in electronic healthcare records, causing residual confounding bias. [Using directed acyclic graphs to detect limitations of traditional regression in longitudinal studies](#) (Int J Public Health 2010;55:701-3) reviews confounding and intermediate effects in longitudinal data and introduces causal graphs to understand the relationships between the variables in an epidemiological study.

Unmeasured confounding can be adjusted for only through randomisation. When this is not possible, as most often in pharmacoepidemiological studies, the potential impact of residual confounding on the results should be estimated and considered in the discussion.

[Sensitivity analysis and external adjustment for unmeasured confounders in epidemiologic database studies of therapeutics](#) (Pharmacoepidemiol Drug Saf 2006;15(5):291-303) provides a systematic approach to sensitivity analyses to investigate the impact of residual confounding in pharmacoepidemiological studies that use healthcare utilisation databases. In the article, four basic approaches to sensitivity analysis were identified: (1) sensitivity analyses based on an array of informed assumptions; (2) analyses to identify the strength of residual confounding that would be necessary to explain an observed drug-outcome association; (3) external adjustment of a drug-outcome association given additional information on single binary confounders from survey data using algebraic solutions; (4) external adjustment considering the joint distribution of multiple confounders of any distribution from external sources of information using propensity score calibration. The paper concludes that sensitivity analyses and external adjustments can improve our understanding of the effects of drugs in epidemiological database studies. With the availability of easy-to-apply spreadsheets (e.g. at <http://www.drugepi.org/dope-downloads/>), sensitivity analyses should be used more frequently, substituting qualitative discussions of residual confounding.

The amount of bias in exposure-effect estimates that can plausibly occur due to residual or unmeasured confounding has been debated. [The impact of residual and unmeasured confounding in epidemiologic studies: a simulation study](#) (Am J Epidemiol 2007;166:646–55) considers the extent and patterns of bias in estimates of exposure-outcome associations that can result from residual or unmeasured confounding, when there is no true association between the exposure and the outcome. With plausible assumptions about residual and unmeasured confounding, effect sizes of the magnitude frequently reported in observational epidemiological studies can be generated. This study also highlights the need to perform sensitivity analyses to assess whether unmeasured and residual confounding are likely problems. Another important finding of this study was that when confounding factors (measured or unmeasured) are interrelated (e.g. in situations of confounding by indication), adjustment for a few factors can almost completely eliminate confounding.

5.3. Methods to handle bias and confounding

5.3.1. New-user designs

New user (incident user) designs can avoid prevalence bias by restricting the analysis to persons under observation at the start of the current course of treatment, therefore with the same baseline

risk. [Evaluating medication effects outside of clinical trials: new-user designs](#) (Am J Epidemiol 2003;158 (9):915–20). In addition to defining new-user designs, the article explains how they can be implemented as case-control studies and describes the logistical and sample size limitations involved.

5.3.2. Case-only designs

Case-only designs reduce confounding by using the exposure history of each case as its own control and thereby eliminate confounding by characteristics that are constant over time, as demographics, socio-economic factors, genetics and chronic diseases.

A simple form of a case-only design is the symmetry analysis (initially described as prescription sequence symmetry analysis), introduced as a screening tool in [Evidence of depression provoked by cardiovascular medication: a prescription sequence symmetry analysis](#) (Epidemiology 1996;7(5):478-84). In this study, the risk of depression associated with cardiovascular drugs was estimated by analysing the non-symmetrical distribution of prescription orders for cardiovascular drugs and antidepressants.

The case-crossover design studies transient exposures with acute effects ([The Case-Crossover Design: A Method for Studying Transient Effects on the Risk of Acute Events](#). Am J Epidemiol 1991;133:144-53) and [The case-time-control design](#) (Epidemiology 1995;6(3):248-53). It uses exposure history data from a traditional control group to estimate and adjust for the bias from temporal changes in prescribing ([Case-crossover and Case-Time-Control Designs as Alternatives in Pharmacoepidemiologic Research](#). Pharmacoepidemiol Drug Saf 1997; Suppl 3. S51-S59). However, if not well matched, the control group may reintroduce selection bias as discussed in [Confounding and exposure trends in case-crossover and case-time-control designs](#) (Epidemiology. 1996;7:231-9). In this situation, a 'case-time-control' method may be helpful as explained in [Future cases as present controls to adjust for exposure trend bias in case-only studies](#) (Epidemiology 2011;22:568–74).

The self-controlled case series (SCCS) design was primarily developed to investigate the association between a vaccine and an adverse event but is increasingly used to study drug exposure. In this design, the observation period following each exposure for each case is divided into risk period(s) (e.g. number(s) of days immediately following each exposure) and a control period (e.g. the remaining observation period). Incidence rates within the risk period after exposure are compared with incidence rates within the control period.

The [Tutorial in biostatistics: the self-controlled case series method](#) (Stat Med 2006; 25(10):1768-97) and the associated website <http://statistics.open.ac.uk/sccs> explain how to fit SCCS models using standard statistical packages.

Like cohort or case-control studies, the SCCS method remains, however, susceptible to confounding by indication, at least if the indication varies over time. Relevant time intervals for the risk and control periods need also to be defined and this may become complex, e.g. with primary vaccination with several doses. The bias introduced by inaccurate specification of the risk window is discussed and a data-based approach for identifying the optimal risk windows is proposed in [Identifying optimal risk windows for self-controlled case series studies of vaccine safety](#) (Stat Med 2011; 30(7):742-52).

The SCCS also assumes that the event itself does not affect the chance of being exposed. The pseudolikelihood method developed to address this possible issue is described in [Cases series analysis for censored, perturbed, or curtailed post-event exposures](#) (Biostatistics 2009; 10(1): 3-16). Based on a review of 40 vaccine studies, [Use of the self-controlled case-series method in vaccine safety studies: review and recommendations for best practice](#) (Epidemiol Infect

2011;139(12):1805-17) assesses how the SCCS method has been used, highlights good practice and gives guidance on how the method should be used and reported. Using several methods of analysis is recommended, as it can reinforce conclusions or shed light on possible sources of bias when these differ for different study designs.

[Within-person study designs had lower precision and greater susceptibility to bias because of trends in exposure than cohort and nested case-control designs](#) (J Clin Epidemiol 2012;65(4):384-93) compares cohort, case-control, case-cross-over and SCCS designs to explore the association between thiazolidinediones and the risks of heart failure and fracture and anticonvulsants and the risk of fracture. The self-controlled case-series and case-cross over designs were more susceptible to bias, but this bias was removed when follow-up was sampled both before and after the outcome, or when a case-time-control design was used.

[When should case-only designs be used for safety monitoring of medicinal products?](#)

(Pharmacoepidemiol Drug Saf 2012;21(Suppl. 1):50-61) compares the SCCS and case-crossover methods as to their use, strength and major difference (directionality). It concludes that case-only analyses of intermittent users complement the cohort analyses of prolonged users because their different biases compensate for one another. It also provides recommendations on when case-only designs should and should not be used for drug safety monitoring. [Empirical performance of the self-controlled case series design: lessons for developing a risk identification and analysis system](#) (Drug Saf 2013;36(Suppl. 1):S83-S93) evaluates the performance of the SCCS design using 399 drug-health outcome pairs in 5 observational databases and 6 simulated datasets. Four outcomes and five design choices were assessed.

In [Persistent User Bias in Case-Crossover Studies in Pharmacoepidemiology](#). (Am J Epidemiol. 2016 Oct 25., Epub ahead of print) it was demonstrated that case-crossover studies of drugs that may be used indefinitely are biased upward. This bias is alleviated, but not removed completely, by using a control group.

5.3.3. Disease risk scores

An approach to controlling for a large number of confounding variables is to summarise them in a single multivariable confounder score. [Stratification by a multivariate confounder score](#) (Am J Epidemiol 1976;104:609-20) shows how control for confounding may be based on stratification by the score. An example is a disease risk score (DRS) that estimates the probability or rate of disease occurrence conditional on being unexposed. The association between exposure and disease is then estimated with adjustment for the disease risk score in place of the individual covariates.

DRSs are however difficult to estimate if outcomes are rare. [Use of disease risk scores in pharmacoepidemiologic studies](#) (Stat Methods Med Res 2009;18:67-80) includes a detailed description of their construction and use, a summary of simulation studies comparing their performance to traditional models, a comparison of their utility with that of propensity scores, and some further topics for future research. [Disease risk score as a confounder summary method: systematic review and recommendations](#) (Pharmacoepidemiol Drug Saf 2013;22(2):122-29), examines trends in the use and application of DRS as a confounder summary method and shows large variation exists with differences in terminology and methods used.

In [Role of disease risk scores in comparative effectiveness research with emerging therapies](#) (Pharmacoepidemiol Drug Saf. 2012 May;21 Suppl 2:138-47) it is argued that DRS may have its place when studying drugs that are recently introduced to the market. In such situations, as characteristics of users change rapidly, exposure propensity scores (see below) may prove highly unstable. DRSs based mostly on biological associations would be more stable. However, DRS

models are still sensitive to misspecification as discussed in [Adjusting for Confounding in Early Postlaunch Settings: Going Beyond Logistic Regression Models](#) (Epidemiology. 2016;27:133-42).

5.3.4. Propensity scores

Databases used in pharmacoepidemiological studies often include records of prescribed medications and encounters with medical care providers, from which one can construct surrogate measures for both drug exposure and covariates that are potential confounders. It is often possible to track day-by-day changes in these variables. However, while this information can be critical for study success, its volume can pose challenges for statistical analysis.

A propensity score (PS) is analogous to the disease risk score in that it combines a large number of possible confounders into a single variable (the score). The exposure propensity score (EPS) is the conditional probability of exposure to a treatment given observed covariates. In a cohort study, matching or stratifying treated and comparison subjects on EPS tends to balance all of the observed covariates. However, unlike random assignment of treatments, the propensity score may not balance unobserved covariates. [Invited Commentary: Propensity Scores](#) (Am J Epidemiol 1999;150:327–33) reviews the uses and limitations of propensity scores and provide a brief outline of the associated statistical theory. The authors present results of adjustment by matching or stratification on the propensity score.

[High-dimensional Propensity Score Adjustment in Studies of Treatment Effects Using Healthcare Claims Data](#) (Epidemiol 2009; 20(4):512-22) discusses the high dimensional propensity score (hd-PS) model approach. It attempts to empirically identify large numbers of potential confounders in healthcare databases and, by doing so, to extract more information on confounders and proxies. [Covariate selection in high-dimensional propensity score analyses of treatment effects in small samples](#) (Am J Epidemiol 2011;173:1404-13) evaluates the relative performance of hd-PS in smaller samples. [Confounding adjustment via a semi-automated high-dimensional propensity score algorithm: an application to electronic medical records](#) (Pharmacoepidemiol Drug Saf 2012;20:849-57) evaluates the use of hd-PS in a primary care electronic medical record database. In addition, the article [Using high-dimensional propensity score to automate confounding control in a distributed medical product safety surveillance system](#) (Pharmacoepidemiol Drug Saf 2012;21(S1):41-9) summarises the application of this method for automating confounding control in sequential cohort studies as applied to safety monitoring systems using healthcare databases and also discusses the strengths and limitations of hd-PS.

Most cohort studies match patients 1:1 on the propensity score. Increasing the matching ratio may increase precision but also bias. [One-to-many propensity score matching in cohort studies](#) (Pharmacoepidemiol Drug Saf. 2012;21(S2):69-80) tests several methods for 1:n propensity score matching in simulation and empirical studies and recommends using a variable ratio that increases precision at a small cost of bias. [Matching by propensity score in cohort studies with three treatment groups](#) (Epidemiology 2013;24(3):401-9) develops and tests a 1:1:1 propensity score matching approach offering a way to compare three treatment options.

The use of several measures of balance for developing an optimal propensity score model is described in [Measuring balance and model selection in propensity score methods](#) (Pharmacoepidemiol Drug Saf 2011;20:1115-29) and further evaluated in [Propensity score balance measures in pharmacoepidemiology: a simulation study](#) (Pharmacoepidemiol Drug Saf 2014; Epub 2014 Jan 29). In most situations, the standardised difference performs best and is easy to calculate (see [Balance measures for propensity score methods: a clinical example on beta-agonist use and the risk of myocardial infarction](#) (Pharmacoepidemiol Drug Saf 2011;20(11):1130-7) and [Reporting of covariate selection and balance assessment in propensity score analysis is suboptimal: a systematic review](#) (J Clin Epidemiol. 2015;68(2):112-21)). [Metrics for covariate balance in cohort](#)

[studies of causal effects](#) (Stat Med 2013; 33:1685-99) shows in a simulation study that the c-statistics of the PS model after matching and the general weighted difference perform as well as the standardized difference and are preferred when an overall summary measure of balance is requested.

[Performance of propensity score calibration – a simulation study](#) (Am J Epidemiol 2007; 165(10):1110-8) introduces 'propensity score calibration' (PSC). This technique combines propensity score matching methods with measurement error regression models to address confounding by variables unobserved in the main study. This is done by using additional covariate measurements observed in a validation study, which is often a subset of the main study.

[Treatment effects in the presence of unmeasured confounding: dealing with observations in the tails of the propensity score distribution--a simulation study](#) (Am J Epidemiol. 2010; 172(7):843–54) demonstrates how 'trimming' of the propensity score eliminates subjects who are treated contrary to prediction and their exposed/unexposed counterparts, thereby reducing bias by unmeasured confounders.

Although in most situations propensity score models, with the exception of hd-PS, do not have any advantages over conventional multivariate modelling in terms of adjustment for identified confounders, several other benefits may be derived. Propensity score methods may help to gain insight into determinants of treatment including age, frailty and comorbidity and to identify individuals treated against expectation. A statistical advantage of PS analyses is that if exposure is not infrequent it is possible to adjust for a large number of covariates even if outcomes are rare, a situation often encountered in drug safety research. Furthermore, assessment of the PS distribution may reveal non-positivity. An important limitation of PS is that it is not directly amenable for case-control studies.

5.3.5. Instrumental variables

Instrumental variable (IV) methods were invented over 70 years ago but were used by epidemiologists only recently. Over the past decade or so, non-parametric versions of IV methods have appeared that connect IV methods to causal and measurement-error models important in epidemiological applications. [An introduction to instrumental variables for epidemiologists](#) (Int J Epidemiol 2000; 29:722-9) presents those developments, illustrated by an application of IV methods to non-parametric adjustment for non-compliance in randomised trials. The author mentions a number of caveats but concludes that IV corrections can be valuable in many situations. Where IV assumptions are questionable, the corrections can still serve as part of the sensitivity analysis or external adjustment. Where the assumptions are more defensible, as in field trials and in studies that obtain validation or reliability data, IV methods can form an integral part of the analysis. A review of IV analysis for observational comparative effectiveness studies suggested that in the large majority of studies, in which IV analysis was applied, one of the assumption could be violated ([Potential bias of instrumental variable analyses for observational comparative effectiveness research](#), Ann Intern Med. 2014; 161(2):131-8).

A proposal for reporting instrumental variable analyses has been suggested in [Commentary: how to report instrumental variable analyses \(suggestions welcome\)](#) (Epidemiology. 2013; 24(3):370-4). In particular the type of treatment effect (average treatment effect/homogeneity condition or local average treatment effect/monotonicity condition) and the testing of critical assumptions for valid IV analyses should be reported. In support of these guidelines, the standardized difference has been proposed to falsify the assumption that confounders are not related to the instrumental variable ([Quantitative falsification of instrumental variables assumption using balance measures](#), Epidemiology. 2014; 25(5):770-2).

The complexity of the issues associated with confounding by indication, channelling and selective prescribing is explored in [Evaluating short-term drug effects using a physician-specific prescribing preference as an instrumental variable](#) (Epidemiology 2006; 17(3):268-75). A conventional, adjusted multivariable analysis, the author showed a higher risk of gastrointestinal toxicity for selective COX-2-inhibitors than for traditional NSAIDs, which is at odds with results from clinical trials. However, a physician-level instrumental variable approach (a time-varying estimate of a physician's relative preference for a given drug, where at least two therapeutic alternatives exist) yielded evidence of a protective effect due to COX-2 exposure, particularly for shorter term drug exposures. Despite the potential benefits of physician-level IVs their performance can vary across databases and strongly depends on the definition of IV used as discussed in [Evaluating different physician's prescribing preference based instrumental variables in two primary care databases: a study of inhaled long-acting beta2-agonist use and the risk of myocardial infarction](#) (Pharmacoepidemiol Drug Saf. 2016; 25 Suppl 1:132-41).

[Instrumental variable methods in comparative safety and effectiveness research](#)

(Pharmacoepidemiol Drug Saf 2010; 19:537–54) is a practical guidance on IV analyses in pharmacoepidemiology. [Instrumental variable methods for causal inference](#) (Stat Med. 2014; 33(13):2297-340) is a tutorial, including statistical code for performing IV analysis.

An important limitation of IV analysis is that weak instruments (small association between IV and exposure) lead to decreased statistical efficiency and biased IV estimates as detailed in [Instrumental variables: application and limitations](#) (Epidemiology 2006; 17:260-7). For example, in the above mentioned study on non-selective NSAIDs and COX-2-inhibitors, the confidence intervals for IV estimates were in the order of five times wider than with conventional analysis. [Performance of instrumental variable methods in cohort and nested case-control studies: a simulation study](#) (Pharmacoepidemiol Drug Saf 2014; 2014; 23(2):165-77) demonstrated that a stronger IV-exposure association is needed in nested case-control studies compared to cohort studies in order to achieve the same bias reduction. Increasing the number of controls reduces this bias from IV analysis with relatively weak instruments.

[Selecting on treatment: a pervasive form of bias in instrumental variable analyses](#) (Am J Epidemiol. 2015; 181(3):191-7) warns against bias in IV analysis by including only a subset of possible treatment options.

5.3.6. Prior event rate ratios

Another method proposed to control for unmeasured confounding is the Prior Event Rate Ratio (PERR) adjustment method, in which the effect of exposure is estimated using the ratio of rate ratios (RRs) from periods before and after initiation of a drug exposure as discussed in [Replicated studies of two randomized trials of angiotensin converting enzyme inhibitors: further empiric validation of the 'prior event rate ratio' to adjust for unmeasured confounding by indication](#) (Pharmacoepidemiol Drug Saf. 2008; 17:671-685). For example, when a new drug is launched, direct estimation of the drug's effect observed in the period after launch is potentially confounded. Differences in event rates in the period before the launch between future users and future non-users may provide a measure of the amount of confounding present. By dividing the effect estimate from the period after launch by the effect obtained in the period before launch, the confounding in the second period can be adjusted for. This method requires that confounding effects are constant over time, that there is no confounder-by-treatment interaction, and outcomes are non-lethal events.

[Performance of prior event rate ratio adjustment method in pharmacoepidemiology: a simulation study](#) (Pharmacoepidemiol Drug Saf. 2015; 24:468-477) discusses that the PERR adjustment

method can help to reduce bias as a result of unmeasured confounding in certain situations but that theoretical justification of assumptions should be provided.

5.3.7. Handling time-dependent confounding in the analysis

[Methods for dealing with time-dependent confounding](#) (Stat Med. 2013;32(9):1584-618) provides an overview of how time-dependent confounding can be handled in the analysis of a study. It provides an in-depth discussion of marginal structural models and g-computation.

5.3.7.1. G-estimation

G-estimation is a method for estimating the joint effects of time-varying treatments using ideas from instrumental variables methods. [G-estimation of Causal Effects: Isolated Systolic Hypertension and Cardiovascular Death in the Framingham Heart Study](#) (Am J Epidemiol 1998;148(4):390-401) demonstrates how the G-estimation procedure allows for appropriate adjustment of the effect of a time-varying exposure in the presence of time-dependent confounders that are themselves influenced by the exposure.

5.3.7.2. Marginal Structural Models (MSM)

The use of Marginal Structural Models can be an alternative to G-estimation. [Marginal Structural Models and Causal Inference in Epidemiology](#) (Epidemiology 2000;11:550-60) introduces MSM, a class of causal models that allow for improved adjustment for confounding in situations of time-dependent confounding.

MSMs have two major advantages over G-estimation. Even if it is useful for survival time outcomes, continuous measured outcomes and Poisson count outcomes, logistic G-estimation cannot be conveniently used to estimate the effect of treatment on dichotomous outcomes unless the outcome is rare. The second major advantage of MSMs is that they resemble standard models, whereas G-estimation does not (see [Marginal Structural Models to Estimate the Causal Effect of Zidovudine on the Survival of HIV-Positive Men](#). Epidemiology 2000;11:561–70).

[Effect of highly active antiretroviral therapy on time to acquired immunodeficiency syndrome or death using marginal structural models](#) (Am J Epidemiol 2003;158:687-94) provides a clear example in which standard Cox analysis failed to detect a clinically meaningful net benefit of treatment because it does not appropriately adjust for time-dependent covariates that are simultaneously confounders and intermediate variables. This net benefit was shown using a marginal structural survival model. In [Time-dependent propensity score and collider-stratification bias: an example of beta\(2\)-agonist use and the risk of coronary heart disease](#) (Eur J Epidemiol 2013;28(4):291-9), various methods to control for time-dependent confounding are compared in an empirical study on the association between inhaled beta-2-agonists and the risk of coronary heart disease. MSMs resulted in slightly reduced associations compared to standard Cox-regression.

Beyond the approaches proposed above, traditional and efficient approaches to deal with time dependent variables should be considered in the design of the study, such as nested case control studies with assessment of time varying exposure windows.

5.4. Effect measure modification and interaction

Effect measure modification and interaction are often encountered in epidemiological research and it is important to recognize their occurrence. The difference between them is rather subtle and has been described in [On the distinction between interaction and effect modification](#) (Epidemiology. 2009;20:863–71). Effect measure modification occurs when the measure of an effect changes over

values of some other variable (which does not necessarily need to be a causal factor). Interaction occurs when two exposures contribute to the causal effect of interest, and they are both causal factors. Interaction is generally studied in order to clarify aetiology while effect modification is used to identify populations that are particularly susceptible to the exposure of interest.

To check the presence of effect measure modifier, one can stratify the study population by a certain variable, e.g. by gender, and compare the effects in these subgroups. It is recommended to perform a formal statistical test to assess if there are statistically significant differences between subgroups for the effects, see [CONSORT 2010 Explanation and Elaboration: Updated guidelines for reporting parallel group randomised trials](#) (J Clin Epidemiol 2010; 63(8):e1-37) and [Interaction revisited: the difference between two estimates](#) (BMJ 2003; 326:219). The study report should explain which method was used to examine these differences and specify which subgroup analyses were predefined in the study protocol and which ones were performed while analysing the data ([Strengthening the Reporting of Observational Studies in Epidemiology \(STROBE\): explanation and elaboration](#). Epidemiology 2007; 18:805-35).

The presence of effect measure modification depends on which measure is used in the study (absolute or relative) and can be measured in two ways: on an additive scale (based on risk differences [RD]), or on a multiplicative scale (based on relative risks [RR]). From the perspective of public health and clinical decision making, the additive scale is usually considered the most appropriate. An example of potential effect modifier in studies assessing the risk of occurrence of events associated with recent drug use is the past use of the same drug. This is shown in [Evidence of the depletion of susceptibles effect in non-experimental pharmacoepidemiologic research](#) (J Clin Epidemiol 1994; 47(7): 731-7) in the context of a hospital-based case-control study on NSAIDs and the risk of upper gastrointestinal bleeding.

For the evaluation of interaction, the standard measure is the relative excess risk due to interaction (RERI), as explained in the textbook *Modern Epidemiology* (K. Rothman, S. Greenland, T. Lash. 3rd Edition, Lippincott Williams & Wilkins, 2008). Other measures of interaction include the attributable proportion (A) and the synergy index (S). With sufficient sample size, most interaction tests perform similarly with regard to type 1 error rates and power according to [Exploring interaction effects in small samples increases rates of false-positive and false-negative findings: results from a systematic review and simulation study](#) (J Clin Epidemiol 2014; 67(7):821-9).

Due to surrounding confusion about these terms, it is important that effect measure modification and interaction analysis are presented in a way that is easy to interpret and allows readers to reproduce the analysis. For recommendations regarding reporting, [Strengthening the Reporting of Observational Studies in Epidemiology \(STROBE\): explanation and elaboration](#) (Epidemiology 2007; 18:805-35) and [Recommendations for presenting analyses of effect modification and interaction](#) (Int J Epidemiol 2012; 41:514-20) are useful resources and their recommendations for the presentation of results are summarized below:

1. Separate effects (rate ratios, odds ratios or risk differences, with confidence intervals) of the exposure of interest (e.g. drug), of the effect modifier (e.g. gender) and of their joint effect using one single reference category (preferably the stratum with the lowest risk of the outcome) as suggested in [Estimating measures of interaction on an additive scale for preventive exposures](#) (Eur J Epidemiol 2011; 26(6):433-8) as this gives enough information to the reader to calculate effect modification on an additive and multiplicative scale;
2. Effects of the exposure within strata of the potential effect modifier;
3. Measures of effect modification on both additive (e.g. RERI) and multiplicative (e.g. S) scales including confidence intervals;

- List of the confounders for which the association between exposure and outcome was adjusted for.

5.5. Ecological analyses and case-population studies

Ecological analyses should not be considered hypothesis testing studies. As illustrated in [Control without separate controls: evaluation of vaccine safety using case-only methods](#) (Vaccine 2004; 22(15-16):2064-70), they assume that a strong correlation between the trend in an indicator of an exposure (vaccine coverage in this example) and the trend in incidence of a disease (trends calculated over time or across geographical regions) is consistent with a causal relationship. Such comparisons at the population level may only generate hypotheses as they do not allow controlling for time-related confounding variables, such as age and seasonal factors. Moreover, they do not establish that the vaccine effect occurred in the vaccinated individuals.

Case-population studies are a form of ecological studies where cases are compared to an aggregated comparator consisting of population data. [The case-population study design: an analysis of its application in pharmacovigilance](#) (Drug Saf 2011; 34(10):861-8) explains its design and its application in pharmacovigilance for signal generation and drug surveillance. More recently, the design was explained in the textbook 'Drug Utilization Research - Methods and Applications' (Wettermark B, Di Martino M, Elsevier M. Study designs in drug utilization research. An example is a multinational case-population study aiming to estimate population rates of a suspected adverse event using national sales data ([Transplantation for Acute Liver Failure in Patients Exposed to NSAIDs or Paracetamol \(Acetaminophen\)](#) Drug Saf 2013; 36: 135–44). Based on the same study, [Choice of the denominator in case population studies: event rates for registration for liver transplantation after exposure to NSAIDs in the SALT study in France](#) (Pharmacoepidemiol Drug Saf 2013; 22(2): 160-7) compares sales data and healthcare insurance data as denominators to estimate population exposure and found large differences in the event rates. Choosing the wrong denominator in case population studies might, therefore, give erroneous results. The choice of the right denominator will depend on the hazard function of the adverse event.

A pragmatic attitude towards case-population studies is recommended: in situations where nation-wide or region-wide EHRs are available that allow assessing the outcomes and confounders with sufficient validity, a case-population approach is neither necessary nor wanted, as one can perform a population-based cohort or case-control study with adequate control for confounding. In situations where outcomes are difficult to ascertain in EHRs or where such databases do not exist, the case-population design might give an approximation of the absolute and relative risk when both events and exposures are rare. This is limited by the ecological nature of the reference data that restricts the ability to control for confounding to some basic variables, such as sex and age, and precludes an exhaustive control for confounding.

5.6. Pragmatic trials and large simple trials

5.6.1. Pragmatic trials

RCTs are considered the gold standard for demonstrating the efficacy of medicinal products and for obtaining an initial estimate of the risk of adverse outcomes. However, as is well understood, these data are often not necessarily indicative of the benefits, risks or comparative effectiveness of an intervention when used in clinical practice populations. The [IMI GetReal Glossary](#) defines a pragmatic clinical trial (PCT) as 'a study comparing several health interventions among a randomised, diverse population representing clinical practice, and measuring a broad range of health outcomes.' PCTs are focused on evaluating benefits and risks of treatments in patient populations and settings more representative of routine clinical practice. To ensure generalisability,

pragmatic trials should represent the patients to whom the treatment will be applied, for instance, inclusion criteria would be broad (e.g. allowing co-morbidity, co-medication, wider age range), the follow-up would be minimized and allow for treatment switching etc. [Monitoring safety in a phase III real-world effectiveness trial: use of novel methodology in the Salford Lung Study](#) (Pharmacoepidemiol Drug Saf. 2017; 26(3): 344-352) describes the model of a phase III pragmatic RCT where patients were enrolled through primary care practices using minimal exclusion criteria and without extensive diagnostic testing and where potential safety events were captured through patients' electronic health records and in turn triggered review by the specialist safety team.

[Pragmatic explanatory continuum summary \(PRECIS\): a tool to help trial designers](#) (CMAJ 2009; 180: E45-57) is a tool to support pragmatic trial designs and helps define and evaluate the degree of pragmatism. The PRECIS tool has been further refined and now comprises nine domains each scored on a 5 point Likert scale ranging from very explanatory to very pragmatic with an exclusive focus on the issue of applicability ([The PRECIS-2 tool: designing trials that are fit for purpose](#). BMJ 2015; 350: h2147). A checklist and additional guidance is also provided in [Improving the reporting of pragmatic trials: an extension of the CONSORT statement](#) (BMJ 2008; 337 (a2390): 1-8).

5.6.2. Large simple trials

Large simple trials (LSTs) are pragmatic RCTs with minimal data collection protocols that are narrowly focused on clearly defined outcomes important to patients as well as clinicians. Their large sample size provides adequate statistical power to detect even small differences in effects. Additionally, LST's include a follow-up time that mimics normal clinical practice.

LSTs are particularly suited when an adverse event is very rare or with a delayed latency (with a large expected attrition rate), when the population exposed to the risk is heterogeneous (e.g. different indications and age groups), when several risks need to be assessed in the same trial or when many confounding factors need to be balanced between treatment groups. In these circumstances, the cost and complexity of a traditional RCT may outweigh its advantages and LSTs can help keep the volume and complexity of data collection to a minimum.

Outcomes that are simple and objective can also be measured from the routine process of care using epidemiological follow-up methods, for example by using questionnaires or hospital discharge records. LST methodology is discussed in Chapters 36 and 37 of the book *Pharmacoepidemiology* (Strom BL, Kimmel SE, Hennessy S. 5th Edition, Wiley, 2012), which includes a list of conditions appropriate for the conduct of a LST and a list of conditions which make a LST feasible. Examples of published LSTs are [Assessment of the safety of paediatric ibuprofen: a practitioner based randomised clinical trial](#) (JAMA 1995; 279: 929-33) and [Comparative mortality associated with ziprasidone and olanzapine in real-world use among 18,154 patients with schizophrenia: The Zodiac Observational Study of Cardiac Outcomes \(ZODIAC\)](#) (Am J Psychiatry 2011; 168(2): 193-201).

Note that the use of the term 'simple' in the expression 'LST' refers to data structure and not data collection. It is used in relation to situations in which a small number of outcomes are measured. The term may therefore not adequately reflect the complexity of the studies undertaken.

5.6.3. Randomised database studies

Randomised database studies can be considered a special form of an LST where patients included in the trial are enrolled in a healthcare system with electronic records. Eligible patients may be identified and flagged automatically by the software, with the advantage of allowing comparison of included and non-included patients. Database screening or record linkage can be used to detect and measure outcomes of interest otherwise assessed through the normal process of care. Patient

recruitment, informed consent and proper documentation of patient information are hurdles that still need to be addressed in accordance with the applicable legislation for RCTs. Randomised database studies attempt to combine the advantages of randomisation and observational database studies. These and other aspects of randomised database studies are discussed in [The opportunities and challenges of pragmatic point-of-care randomised trials using routinely collected electronic records: evaluations of two exemplar trials](#) (Health Technol Assess. 2014; 18(43): 1-146) which illustrates the practical implementation of randomised studies in general practice databases.

There are few published examples of randomised database studies, but this design could become more common in the near future with the increasing computerisation of medical records. [Pragmatic randomised trials using routine electronic health records: putting them to the test](#) (BMJ 2012; 344:e55) describes a project to implement randomised trials in the everyday clinical work of general practitioners, comparing treatments that are already in common use, and using routinely collected electronic healthcare records both to identify participants and to gather results.

A particular form of randomised databases studies is the registry-based randomised trial, which uses an existing registry as platform for the identification of cases, randomisation and follow-up. The editorial [Randomized Registry Trial — The Next Disruptive Technology in Clinical Research?](#) (N Engl J Med 2013; 369:1579-1581) introduces the concept. This hybrid design tries to achieve both internal and external validity by using a robust design (RCT) in a data source with higher generalisability (registries). Other examples are the TASTE trial that followed patients long-term using data from a Scandinavian registry ([Thrombus aspiration during ST-segment elevation myocardial infarction](#). N. Engl J Med. 2013; 369(17): 1587-97) and A registry-based randomized trial comparing radial and femoral approaches in women undergoing percutaneous coronary intervention: the SAFE-PCI for Women (Study of Access Site for Enhancement of PCI for Women) trial (JACC Cardiovasc Interv. 2014 Aug). A potential limitation of randomised registry trials is the routine collection of data on outcomes needed for the trial, such as information on surrogate markers and adverse events.

5.7. Systematic reviews and meta-analysis

There may be results from more than one study with the same or similar research objective, and identification and integration of this evidence can extend our understanding of the issue. The focus of this activity may be to learn from the diversity of designs, results and associated gaps in knowledge as well as to obtain overall risk estimates. An example is the meta-analysis of results of individual studies with potentially different design e.g. [Variability in risk of gastrointestinal complications with individual NSAIDs: results of a collaborative meta-analysis](#) (BMJ 1996; 312:1563-6), which compared the relative risks of serious gastrointestinal complications reported with individual NSAIDs by conducting a systematic review of twelve hospital and community based case-control and cohort studies, and found a relation between use of the drugs and admission to hospital for haemorrhage or perforation.

A systematic literature review aims to collect all empirical evidence that fits pre-specified eligibility criteria to answer a specific research question. These reviews use systematic and explicit methods to identify and critically appraise relevant research, and to analyse the data included in the review. A meta-analysis involves the use of statistical techniques to integrate and summarize the results of identified studies.

Systematic review and meta-analysis of observational studies and other epidemiological sources are becoming as common as those of RCTs. [Challenges in systematic reviews that assess](#)

[treatment harms](#) (Ann Intern Med 2005;142:1090-9) explains the different reasons why both are important in providing relevant information and knowledge for pharmacovigilance.

A detailed guidance on the methodological conduct of systematic reviews and meta-analysis is reported in [Annex 1](#) of this guide. This guidance includes links to other relevant resources.

It should be noted that meta-analysis, even of randomised controlled trials, shares characteristics with observational research: the studies are often produced according to an unplanned process and subjective processes are involved in selection of studies to include. Careful planning in design of a meta-analysis and pre-specification of selection criteria, outcomes and analytical methods before review of any study results may thus add appreciably to the confidence that is placed in the results. A further useful reference is the CIOMS Working Group X [Guideline on Evidence Synthesis and Meta-Analysis for Drug Safety](#) (Geneva 2016).

5.8. Signal detection methodology and application

A general overview of methods for signal detection and recommendations for their application are provided in the report of the CIOMS Working Group VIII [Practical Aspects of Signal Detection in Pharmacovigilance](#) and empirical results on various aspects of signal detection obtained from the IMI PROTECT project have been summarised in [Good Signal Detection Practices: Evidence from IMI PROTECT](#) (Drug Saf. 2016;39:469-90).

Quantitative analysis of spontaneous adverse drug reaction reports is increasingly used in drug safety research. [The role of data mining in pharmacovigilance](#) (Expert Opin Drug Saf 2005;4(5):929-48) explains how signal detection algorithms work and addresses questions regarding their validation, comparative performance, limitations and potential for use and misuse in pharmacovigilance. [Quantitative signal detection using spontaneous ADR reporting](#) (Pharmacoepidemiol Drug Saf 2009;18:427-36) describes the core concepts behind the most common methods, the proportional reporting ratio (PRR), reporting odds ratio (ROR), information component (IC) and empirical Bayes geometric mean (EBGM). The authors also discuss the role of Bayesian shrinkage in screening spontaneous reports and the importance of changes over time in screening the properties of the measures. Additionally, they discuss major areas of controversy (such as stratification and evaluation and implementation of methods) and give some suggestions as to where emerging research is likely to lead. [Data mining for signals in spontaneous reporting databases: proceed with caution](#) (Pharmacoepidemiol Drug Saf 2007;16:359-65) reviews data mining methodologies and their limitations and provides useful points to consider before incorporating data mining as a routine component of any pharmacovigilance program. An empirical evaluation of several disproportionality methods in a number of different spontaneous reporting databases is given in [Comparison of Statistical Detection Methods within and across Spontaneous Reporting Databases](#) (Drug Saf 2015; 38(6): 577-87).

Methods such as multiple logistic regression (that may use propensity score-adjustment) have the theoretical capability to reduce masking and confounding by co-medication and underlying disease.

[Performance of Pharmacovigilance Signal Detection Algorithms for the FDA Adverse Event Reporting System](#) (Clin Pharmacol Ther 2013;93(6):539-46) describes the performance of signal-detection algorithms for spontaneous reports in the US FDA adverse event reporting system against a benchmark constructed by the [Observational Medical Outcomes Partnership OMOP](#). It concludes that logistic regression performs better than traditional disproportionality analysis. Other studies have addressed similar or related matters: for example, [Large scale regression-based pattern discovery: the example of screening the WHO global drug safety database](#) (Stat. Anal. Data Min 2010; 3, 197-208), [Are all quantitative postmarketing signal detection methods equal?](#) [Performance characteristics of logistic regression and Multi-item Gamma Poisson Shrinker](#)

(Pharmacoepidemiol. Drug Saf. 2012; 21, 622–630 and [Data-driven prediction of drug effects and interactions](#) (Sci. Transl. Med. 2012 4, 125ra31). The letter [Logistic regression in signal detection: Another Piece added to the Puzzle](#) (Clin Pharmacol Ther 2013;94 (3):312) highlights the variability of results obtained in different studies based on this method and the daunting computational task it requires. More work is needed on its value for pharmacovigilance in the real world setting.

A more recent proposal involves a broadening of the basis for computational screening of individual case safety reports, by considering multiple aspects of the strength of evidence in a predictive model. This approach combines disproportionality analysis with features such as the number of well-documented reports, the number of recent reports and geographical spread of the case series ([Improved statistical signal detection in pharmacovigilance by combining multiple strength-of-evidence aspects in vigiRank](#). Drug Saf 2014;378):617–28). In a similar spirit, logistic regression has been proposed to combine a disproportionality measure with a measure of unexpectedness for the time-to-onset distribution ([Use of logistic regression to combine two causality criteria for signal detection in vaccine spontaneous report data](#), Drug Saf 2014;37(12):1047-57).

Many statistical signal detection algorithms disregard the underlying diversity and give equal weight to reports on all patients when computing the expected number of reports for a drug-event pair. This may render them vulnerable to confounding and distortions due to effect modification, and could result in true signals being masked or false associations being flagged as potential signals. Stratification and/or subgroup analyses might address these issues, and whereas stratification is implemented in some standard software packages, routine use of subgroup analyses is less common. [Performance of Stratified and Subgrouped Disproportionality Analyses in Spontaneous Databases](#) (Drug Saf 2016; 39: (4):355-364) performed a comparison across a range of spontaneous report databases and covariates and found subgroup analyses to improve first pass signal detection, whereas stratification did not; subgroup analyses by patient age and country of origin were found to bring greatest value.

Masking is a statistical issue by which true signals of disproportionate reporting are hidden by the presence of other products in the database. While it is not currently perfectly understood, publications have described methods assessing the extent and impact of the masking effect of measures of disproportionality. They include [A conceptual approach to the masking effect of measures of disproportionality](#) (Pharmacoepidemiol Drug Saf 2014;23(2):208-17), with an application described in [Assessing the extent and impact of the masking effect of disproportionality analyses on two spontaneous reporting systems databases](#) (Pharmacoepidemiol Drug Saf 2014;23(2):195-207), [Outlier removal to uncover patterns in adverse drug reaction surveillance - a simple unmasking strategy](#) (Pharmacoepidemiol Drug Saf 2013;22(10):1119-29) and [A potential event-competition bias in safety signal detection: results from a spontaneous reporting research database in France](#) (Drug Saf 2013;36(7):565-72). The value of these methods in practice needs to be further investigated.

The [Guideline on the use of statistical signal detection methods in the Eudravigilance data analysis system](#) describes quantitative methods of disproportionality implemented in signal detection by the European Medicines Agency (EMA) together with the elements for their interpretation and their potential limitations in the frame of pharmacovigilance. It encompasses the use of quantitative methods in [EudraVigilance](#) applied to the evaluation of Individual Case Safety Reports (ICSRs) originating from healthcare professionals and involving authorised medicinal products.

A time-consuming step in signal detection of adverse reactions is the determination of whether an effect is already recorded in the product information. A database which can be searched for this information allows filtering or flagging reaction monitoring reports for signals related to unlisted reactions, thus improving considerably the efficiency of the signal detection process by allowing a comparison only to drugs for which the adverse event was not considered to be causally related. In

research, it permits an evaluation of the effect of background restriction on the performance of statistical signal detection. An example of such database is the [PROTECT Database of adverse drug reactions \(EU SPC ADR database\)](#), a structured Excel database of all adverse drug reactions (ADRs) listed in section 4.8 of the Summary of Product Characteristics (SPC) of medicinal products authorised in the European Union (EU) according to the centralised procedure, based exclusively on the [Medical Dictionary for Regulatory Activities \(MedDRA\)](#) terminology.

Other large observational databases such as claims and electronic medical records databases are potentially useful as part of a larger signal detection and refinement strategy. [Modern methods of pharmacovigilance: detecting adverse effects of drugs](#) (Clin Med 2009;9(5):486-9) describes the strengths and weaknesses of different data sources for signal detection (spontaneous reports, electronic patient records and cohort-event monitoring). A number of studies have considered the use of observational data in electronic systems that complement existing methods of safety surveillance e.g. the [PROTECT](#), [OHDSI](#) and [Sentinel](#) projects.

The EU [Guideline on good pharmacovigilance practices \(GVP\) Module IX - Signal Management](#) defines signal management as the set of activities performed to determine whether, based on an examination of individual case safety reports (ICSRs), aggregated data from active surveillance systems or studies, literature information or other data sources, there are new risks associated with an active substance or a medicinal product or whether risks have changed. Signal management covers all steps from detecting signals (signal detection), through their validation and confirmation, analysis, prioritisation and assessment to recommending action, as well as the tracking of the steps taken and of any recommendations made.

The FDA's [Guidance for Industry-Good Pharmacovigilance Practices and Pharmacoepidemiologic Assessment](#) provides best practice for documenting, assessing and reporting individual case safety reports and case series and for identifying, evaluating, investigating and interpreting safety signals, including recommendations on data mining techniques and use of pharmacoepidemiological studies.

6. The statistical analysis plan

6.1. General considerations

There is a considerable body of literature explaining statistical methods for observational studies but very little addressing the statistical analysis plan. A clear guide to general principles and the need for a plan is given in *Design of Observational Studies* (P.R. Rosenbaum, Springer Series in Statistics, 2010. Chapter18), which also gives useful advice on how to test complex hypotheses in a way that controls the chances of drawing incorrect conclusions.

Planning analyses for randomised clinical trials is covered in a number of publications. These often give checklists of the component parts of an analysis plan and much of this applies equally to non-randomised design. A good reference in this respect is the [International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use \(ICH\). ICH E9 'Statistical Principles for Clinical Trials'](#). While specific guidance on the statistical analysis plan for epidemiological studies is sparse, the following principles will apply to most of the studies.

- A study is generally designed with the objective of addressing a set of research questions. However, the initial product of a study is a set of numerical and categorical observations that do not usually provide a direct answer to the questions that the study is designed to address. The statistical analysis plan details the mathematical transformations that will be performed on the observed data in the study and the patterns of results that will be interpreted as supporting alternative answers to the questions. It will also explain the rationale behind this decision

making process and the way that this rationale has influenced the study design. An important part of the statistical analysis plan will explain how problems in the data will be handled in such calculations, for example missing or partial data.

- The statistical analysis plan should be sufficiently detailed so that it can be followed in the same way by any competent analyst. Thus it should provide clear and complete templates for each analysis.
- Pre-specification of statistical and epidemiological analyses can be challenging for data that are not collected specifically to answer the study questions. This is often the case in observational studies. However, thoughtful specification of the way missing values will be handled or the use of a small part of the data as a pilot set to guide analysis can be useful techniques to overcome such problems. A feature common to most studies is that some not pre-specified analyses will be performed in response to observations in the data to help interpretation of results. It is important to distinguish between such data-driven analyses and the pre-specified findings. Post-hoc modifications to the analysis strategy should be noted and explained. The statistical analysis plan provides a confirmation of this process.

A particular concern in retrospective studies is that decisions about the analysis should be made blinded to any knowledge of the results. This should be a consideration in the study design, particularly when feasibility studies are to be performed to inform the design phase. Feasibility studies should be independent of the main study results.

6.2. Statistical analysis plan structure

The statistical and epidemiological analysis plan is usually structured to reflect the protocol and will address, where relevant, the following points:

1. A description of the study data sources, linkage methods, and study design including intended study population, inclusion and exclusion criteria and study period with discussion of strengths and weaknesses.
2. Formal definitions of exposure including transformations to determine duration and quantity of exposure.
3. Definition of follow-up and censoring if applicable.
4. Formal definitions of any outcomes, for example 'fatal myocardial infarction' that might be defined as 'death within 30 days of a myocardial infarction'. Outcome variables based on historical data may involve complex transformations to approximate clinical variables not explicitly measured in the dataset used. These transformations should be discriminated from those made to improve the fit of a statistical model. In either case the rationale should be given. In the latter case this will include which tests of fit will be used and under what conditions a transformation will be used.
5. Formal definitions for other variables – e.g. thresholds for abnormal levels of blood parameters. When values of variables for a subject vary with time, care should be given to explaining how the values will be determined at each time point and recorded in the dataset for use in a statistical model.
6. The effect measures and statistical methods used to address each primary and secondary objective.
7. Blinding to exposure variables of evaluators making subjective judgments about the study.
8. Methods of dealing with confounding, such as:

- 8.1. Which confounders will be considered and how they will be defined
 - 8.2. Adjustment for confounders in statistical models
 - 8.3. Restriction in analysis
 - 8.4. Matching, including PS matching
 - 8.5. Self-controlled study designs
 - 8.6. Statistical approach for any selection of a subset of confounders
 - 8.7. Methods for assessing the level of confounding adjustment achieved
 - 8.8. Sensitivity analyses for residual confounding
9. Handling of missing data, including:
 - 9.1. How missing data will be reported;
 - 9.2. Methods of imputation;
 - 9.3. Sensitivity analyses for handling missing data;
 - 9.4. How censored data will be treated, with rationale.
 10. Fit of the model – if considered for a predictive model, including:
 - 10.1. Criteria for assessing fit;
 - 10.2. Alternative models in the event of clear lack of fit.
 11. Interim analyses – if considered:
 - 11.1. Criteria, circumstances and possible drawbacks for performing an interim analysis and possible actions (including stopping rules) that can be taken on the basis of such an analysis
 12. How the achieved patient population will be characterised:
 - 12.1. Description of target population;
 - 12.2. Description of the analysis population if different, e.g. after PS matching or in IV analyses.
 13. Treatment of multiplicity issues not elsewhere covered.
 14. Sample size considerations should be presented, making explicit the data source from which the expected variation of relevant quantities and the clinically relevant differences are derived. It should be noted that in observational studies on data that already exist and where no additional data can be collected, sample size is not preclusive and the ethical injunction against 'underpowered' studies has no obvious force provided the results, in particular the 'absence of effect' and 'insufficient evidence', are properly presented and interpreted.

6.3. Handling of missing data

Missing data, or missing values, occur when no data value is stored for the variable in the current observation. Missing data are a common occurrence and can have a significant effect on the conclusions that can be drawn from the data.

The book *Statistical analysis with missing data* (Little RJA, Rubin DB. 2nd ed., Wiley 2002) describes many aspects of the handling of missing data. The section 'Handling of missing values' in Rothman's *Modern Epidemiology*, 3rd ed. (K. Rothman, S. Greenland, T. Lash. Lippincott Williams & Wilkins, 2008) is a summary of the state of the art, focused on practical issues for epidemiologists. Ways of dealing with such data include complete subject analysis (subjects with missing values are deleted from the analyses) and imputation methods (missing data are predicted based on the observed values and the pattern of missingness). A method commonly used in epidemiology is to create a category of the variable, or an indicator, for the missing values. This practice can be invalid even if the data are missing completely at random and should be avoided ([Indicator and Stratification Methods for Missing Explanatory Variables in Multiple Linear Regression](#). J Am Stat Assoc 1996;91(433): 222–230).

A concise review of methods to handle missing data is also provided in the section 'Missing data' of the *Encyclopedia of Epidemiologic Methods* (Gail MH, Benichou J, Editors. Wiley 2000). Identifying

the pattern of missing data is important as some methods for handling missing data assume a defined pattern of missingness. Biased results may be obtained if it is incorrectly assumed that data are missing at random. In general, it is desirable to show that conclusions drawn from the data are not sensitive to the particular strategy used to handle missing values. To investigate this, it may be helpful to repeat the analysis with a variety of approaches.

Other useful references on handling of missing data include the books *Multiple Imputation for Nonresponse in Surveys* (Rubin DB, Wiley, 1987) and *Analysis of Incomplete Multivariate Data* (Schafer JL, Chapman & Hall/CRC, 1997), and the articles [Using the outcome for imputation of missing predictor values was preferred](#) (J Clin Epi 2006;59(10):1092-101), [Recovery of information from multiple imputation: a simulation study](#) (Emerg Themes Epidemiol 2012;9(1):3) and [Evaluation of two-fold fully conditional specification multiple imputation for longitudinal electronic health record data](#) (Stat Med. 2014;33:3725-37).

7. Quality management

Biomedical research is characterised by a tremendous expansion of knowledge in recent years and quality in biomedical research ultimately impacts on either regulatory practice or medicines development or public health.

Quality is a measure of excellence or a state of being free from defects, deficiencies and significant variations and the quality management includes all the activities that organisations use to direct, control and coordinate quality (International Standards Organization, [ISO 9000](#)). The seven quality management principles (QMPs), *i.e.*, customer focus, leadership, engagement of people, process approach, improvement, evidence-based decision-making and relationship management have been introduced in [ISO Quality management principles](#) and are applicable to pharmacoepidemiological research as well.

A summary of the key principles and methods for quality improvement and measurement and patient safety are presented in [Medical Quality Management: Theory and Practice](#) (American College of Medical Quality, Prathibha Varkey. Jones and Bartlett Publishers International, 2010). Functioning, well documented, and transparent quality management systems will benefit those involved in data collection, management and output production, but also has an impact of public health.

The terms 'quality management', 'quality improvement', and 'performance improvement' are used interchangeably in the healthcare literature. Quality management implies and consists in the following activities: quality planning, quality assurance, quality control and quality improvement

Quality planning is defined as a set of activities whose purpose is to define quality system policies, objectives, and requirements, and to explain how these policies will be applied and achieved, and how these requirements will be met. Quality assurance (QA) defines the standards to be followed in order to meet the quality requirements for a product or service, whereas quality control (QC) ensures that these defined standards are followed at every step. [Quantitative Data Analysis for Quality Control in Strategic Management](#) (*Encyclopedia of Strategic Leadership and Management*, V.C.X. Wang, Editor, 2017:1461-1470), describes the relevant quantitative data analytics to inform quality control: identifying the study's objective, determining the relevant data to collect, choosing appropriate instruments to collect those data, analysing that data, recommending appropriate actions, implementing them, and evaluating the implementation to be used effectively in order to act strategically.

Quality improvement refers to anything that enhances an organisation's ability to meet quality requirements.

Managing the quality would not be possible without risk management strategies aimed at identifying, addressing, prioritising, and eliminating potential sources of failure to achieve objectives. [ISPE GPP](#) assists researchers in adhering to good pharmacoepidemiologic research principles, including the use of pharmacoepidemiologic studies for risk management activities and comparative effectiveness research (CER).

Rules, procedures, roles and responsibilities of QA and QC for clinical trials and biomedical research are well defined and described in many documents, such as Chapter 11 of the book [Principles of Good Clinical Practice](#) (M.J. McGraw, A.N. George, S.P. Shearn, eds., Pharmaceutical Press, London, 2010), the [ICH Guideline for Good Clinical Practice E6\(R1\)](#), the [European Forum for Good Clinical Practice \(EFCGP\) Guidelines](#), the Imperial College Academic Health Science Centre (AHSC)'s [Quality Control and Quality Assurance SOP](#), the article [Quality by Design in Clinical Trials: A Collaborative Pilot With FDA](#) (Therapeutic Innovation & Regulatory Science 2013; 47;161-6), or the article [Guidelines for Quality Assurance in Multicenter Trials: A Position Paper](#) (Control Clin Trials 1998;19(5); 477-93).

For post-authorisation safety studies, the resources are: [Commission Implementing Regulation \(EU\) No 520/2012, FDA's Best Practices for Conducting and Reporting Pharmacoepidemiologic Safety Studies Using Electronic Health Care Data Sets](#) or [ISPE GPP](#) and the [Good Practice in Secondary Data Analysis](#).

The article [Quality Assurance and Quality Control in Longitudinal Studies](#) (Epidemiol Rev 1998, 20(1); 71-80) provides a comprehensive overview of components of QA and QC in multi-centre cohort studies with primary data collection. Such studies typically involve collection of an extensive amount of data for processing over an extended period of time and at several centres, with quality depending on a variety of factors relating to study personnel and equipment. Consequently, the QC process in such studies should be considered an integral part of the design of the study and a condition for the validity of its results. [Quality assurance in non-interventional studies](#) (Ger Med Sci 2009;7:Doc 29: 1-14) proposes measures of quality assurance that can be applied at different stages of non-interventional studies without compromising the character of non-intervention. Chapter 11 'Data Collection and Quality Assurance' of the [AHRQ Registries for Evaluating Patient Outcomes: A User's Guide](#), 3rd Edition, reviews key areas of data collection, cleaning, storing, and quality assurance for registries, with practical examples.

The following articles are practical examples of quality aspects implementation in pharmacovigilance and pharmacoepidemiological as well as other biomedical studies:

- [Training, Quality Assurance, and Assessment of Medical Record Abstraction in a Multisite Study](#) (Am J Epidemiol 2003;157:546-51) describes a practical approach to assurance of good quality control in a large multi-site study.
- [Interviewer Variability – Quality Aspects in a Case–Control Study](#) (Eur J Epidemiol 2006;21(4);267-77) describes the procedures used to reduce interviewer variability, including procedures of quality assurance (i.e. education and training of interviewers and data validity checks) and quality control (i.e. a classification test, annual test interviews, expert case validation and database validation).
- [Establishment of the nationwide Norwegian Prescription Database \(NorPD\) – new opportunities for research in pharmacoepidemiology in Norway](#) (Norsk epidemiologi 2008; 18(2):129-36) describes the quality checks applied to the database.
- [Validation and validity of diagnoses in the General Practice Research Database \(GPRD\): a systematic review](#) (Br J Clin Pharmacol 2010;69:4-14) assesses the quality of the methods used to validate diagnoses in the GPRD. The article contains methodological and reporting

recommendations to further strengthen the use of the GPRD in research that are potentially applicable to other databases.

- [EuroDURG Quality Indicator Meeting \(DURQUIM\)](#) presents a report of a meeting which recommended indicators of prescribing quality in drug utilisation research [report published in full in [Indicators of prescribing quality in drug utilisation research: report of a European meeting \(DURQUIM, 13-15 May 2004\)](#) (Eur J Clin Pharmacol. 2005;60(11):831-4)].
- [Data quality management in pharmacovigilance](#) (Drug Saf 2004;27(12):857-70) focusses on three first steps of data processing cycle (collection and data entry; storage and maintenance; selection, retrieval and manipulation), the different quality dimensions associated with these steps together with examples relevant to pharmacovigilance data.

8. Dissemination and reporting

8.1. Principles of communication

Aspects of research communication and reporting include, but are not limited to, reports to health authorities, sponsors, presentations in scientific fora, scientific publications, patient focused communications and websites.

The [Declaration of Helsinki](#) provides guidance on the registration, publication and dissemination of research results. Every research study involving human subjects must be registered in a publicly accessible database before recruitment of the first subject. A means to achieve this with pharmacoepidemiology studies is through registration of protocols and reports of studies in the [EU PAS Register](#).

8.2. Communication of study results

Important points that are emphasised by the guidelines cited below are:

- Sources of research funding should always be disclosed whether in oral or written presentation.
- A dissemination and communication strategy should be pre-defined as part of the funding contract.
- All results with a scientific or public health impact must be made publicly available without undue delay.
- Quantitative measures of association should be reported rather than just results of testing.

The [ISPE GPP](#) contain a section on communication (section V) which includes a statement that there is an ethical obligation to disseminate findings of potential scientific or public health importance and that research sponsors (government agencies, private sector, etc.) shall be informed of study results in a manner that complies with local regulatory requirements. The [Guidance on the format and content of the final study report of non-interventional post-authorisation safety studies](#) (PASS) provides a template for final study reports that may be applied to any non-interventional PASS, including meta-analyses and systematic reviews. The [FDA's Best Practices for Conducting and Reporting Pharmacoepidemiologic Safety Studies Using Electronic Health Care Data Sets](#) includes a description of all the elements that should be addressed and included in the final study report of such studies.

The [Enhancing the Quality and Transparency of Health Research \(EQUATOR\)](#) network is an international initiative that aims to enhance the reliability and value of the published health research literature. [A catalogue of reporting guidelines for health research](#) (Eur J Clin Invest 2010;40(1):35-53) presents a collection of tools and guidelines available on the [EQUATOR website](#)

relating to resources, education and training to facilitate good research reporting and the development, dissemination and implementation of robust reporting guidelines to increase the accuracy and transparency of health research reporting.

The [Strengthening the Reporting of Observational studies in Epidemiology \(STROBE\) Statement Guidelines for reporting observational studies](#) has established recommendations for improving the quality of reporting of observational studies and seeks to ensure a clear presentation of what was planned, done, and found. Of note, the aim of these guidelines was not to prescribe the reporting of observational research in a rigid format, but to address what should be the essential information contained by a publication on an observational study.

The STROBE statement is designed to apply to all observational studies. In addition, [The Reporting of studies Conducted using Observational Routinely-collected health Data \(RECORD\) Statement](#) (PLoS Med. 2015; 12(10):e1001885) was created as an extension to the STROBE statement to address reporting items specific to observational studies using routinely collected health data. RECORD makes additional recommendations on the reporting of methods of selection for study populations, exposures, outcomes and covariates (including codes or algorithms used), whether validation has been conducted, the level of access to databases used, and data linkages that were required to conduct the study.

The [Meta-analysis of Observational Studies in Epidemiology \(MOOSE\) group](#) has developed a [consensus statement](#) and recommendations for reporting meta-analyses of observational studies in epidemiology. It is equivalent to the [STROBE Statement Guidelines for reporting observational studies](#) and the Consolidated Standards of Reporting Trials [Consolidated Standards for Reporting Trials \(CONSORT\) 2010 Statement](#) for RCTs, in that they have communication as their primary objective and take the form of a list of minimum requirements for adequate reporting. The authors recommend a broad inclusion of studies and conduct of post-hoc sensitivity on the dependence of the results on factors, such as quality of underlying papers, design, accounting for confounders etc. The authors comment on the particular problems in merging observational studies with highly variable sets of confounders that were or were not controlled for, but they do not suggest any solution or give any references to possible ways to address it.

The [Preferred Reporting Items for Systematic Reviews and Meta-analyses \(PRISMA\) Statement](#) is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses consisting of a 27-item checklist and a flow diagram. While focused on randomised trials, PRISMA can also be used as a basis for reporting systematic reviews of other types of research, particularly evaluations of interventions. PRISMA may also be useful for critical appraisal of published systematic reviews, although it is not designed as a quality assessment instrument.

The [Guidelines for Submitting Adverse Event Reports for Publication](#) (Pharmacoepidemiol Drug Saf 2007; 16(5): 581–7) lists the key elements that have to be included when publishing a report of one or more adverse events. These guidelines have been endorsed by the International Society for Pharmacoepidemiology (ISPE) and the International Society of Pharmacovigilance (ISoP) and are available on their web sites.

Additional guidance is provided in the [ENCePP Checklist for Study Protocols](#) and [Code of Conduct](#) and the [IEA GEP](#) guideline that have been reviewed elsewhere in this Guide.

Authorship should conform to the guidelines established by the [International Committee of Medical Journal Editors \(ICJME\) 'Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly work in Medical Journals'](#).

9. Data protection and ethical aspects

9.1. Patient and data protection

In Europe, both EU and national legislation determines what is acceptable with regards to patient data access, data linkage and consent issues, including domains such as human rights and duty of confidentiality. Therefore, while individual data custodians may have differing requirements related to what approvals are needed before data can be released, studies conducted in Europe must meet all applicable EU and national legislation.

The provisions of the legislation on the protection of individuals with regard to the processing of personal data and on free movement of such data, as laid down in [Directive 95/46/EC](#) and [Regulation \(EC\) No 45/2001](#) of the European Parliament and of the Council, need to be followed in the EU. For interventional research, the [Directive 2001/20/EC](#) and the [Guidelines for Good Clinical Practice \(Commission Directive 2005/28/EC\)](#) apply. Directive 2001/20 EC will be repealed on the day of entry into application of the new Clinical Trials Regulation ([Regulation \(EU\) No 536/2014](#)). In addition, marketing authorisation holders (MAHs) and investigators must follow relevant national legislation and guidance of those Member States where the study is being conducted ([Directive 2001/83/EC](#) and [Directive 95/46/EC](#)).

Article 36 of the [Commission Implementing Regulation \(EU\) No. 520/2012](#) specifies that for post-authorisation safety studies (PASS) imposed as an obligation, MAHs shall ensure that all study information is handled and stored in a way that ensure the confidentiality of the study records. The [GVP Module VIII - Post-authorisation safety studies](#) recommends that these provisions should also be applied to PASS voluntarily initiated, managed or financed by a MAH.

The [ISPE Good pharmacoepidemiology practice](#) provides recommendations on the protection of human subjects and refers to the ISPE guidelines on [Data Privacy, Medical Record Confidentiality, and Research in the Interest of Public Health](#). It also recommends that the plans for protecting human subjects should be described in a stand-alone section of the study protocol.

9.2. Scientific integrity and ethical conduct

Principles of scientific integrity and ethical conduct are paramount in any medical research. The [Declaration of Helsinki](#) provides ethical principles addressed primarily to physicians involved in medical research involving human subjects, including research on identifiable human material and data. The [ENCePP Code of Conduct](#) offers standards for scientific independence and transparency of research in pharmacoepidemiology and pharmacovigilance. To this end, the Code of conduct promotes best practice for the interactions between investigators and study funders in critical areas such as planning, conduct and reporting of studies. As a core transparency measure, it recommends that the protocols of all pharmacoepidemiology and pharmacovigilance studies should be registered in the [EU PAS Register](#), ideally before they start, and study findings published irrespective of positive or negative results, to avoid publication bias.

Guided by three core values (best science, strengthening public health, transparency), the [ADVANCE Code of Conduct for Collaborative Vaccine Studies](#) (Vaccine 2017; 35(15):1844-55) includes 45 recommendations across 10 topics (Scientific integrity, Scientific independence, Transparency, Conflicts of interest, Study protocol, Study report, Publication, Subject privacy, Sharing of study data, Research contract). Each topic includes a definition, a set of recommendations and a list of additional reading. The concept of the study team is introduced as a key component of the ADVANCE Code of Conduct with a core set of roles and responsibilities. It also provides direct access to a comprehensive list of relevant guidelines. The [Good Pharmacoepidemiology Practices \(GPP\)](#) of the International Society for Pharmacoepidemiology

(ISPE) proposes practices and procedures that should be considered to help ensure the quality and integrity of pharmacoepidemiological research, including detailed guidance for protocol development, roles and responsibilities, study conduct, communication, reporting of adverse events and archiving. The [Good Epidemiology Practice \(GEP\)](#) of the International Epidemiological Association addresses four general ethical principles for research (Autonomy, Beneficence, Non-maleficence and Justice) and proposes rules for good research behaviour in relation to working with personal data, data documentation, publication, the exercise of judgment and scientific misconduct.

The [CIOMS International Ethical Guidelines for Health-related Research Involving Humans](#) (Geneva: 2016) provides international vetted ethical principles and detailed commentary on how universal ethical principles should be applied, with particular attention to conducting research in low-resource settings. It includes 25 guidelines addressing different topics, settings and population groups concerned by health-related research.

The [Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly work in Medical Journals](#) by the [International Committee of Medical Journal Editors \(ICJME\)](#) include clear statements on ethical principles related to publication in biomedical journals. Authorship and contributorship, editorship, peer review, conflicts of interest, privacy and confidentiality and protection of human subjects and animals in research are addressed.

The [Agency for Healthcare Research and Quality \(AHRQ\)](#) published [Registries to Evaluate Patient Outcomes: a User's guide, Third Edition, 2014](#), which is a reference for establishing, maintaining and evaluating the success of registries created to collect data about patient outcomes. Section II: 'Legal and Ethical Considerations for Registries' is a specific chapter dedicated to ethics, data ownership, and privacy. The concepts within are useful although focused on US law.

10. Specific topics

10.1. Comparative effectiveness research

10.1.1. Introduction

Comparative effectiveness research (CER) is designed to inform health-care decisions at the level of both policy and the individual by comparing the benefits and harms of therapeutic strategies available in routine practice, for the prevention, the diagnosis or the treatment of a given health condition. The interventions under comparison may be related to similar treatments, such as competing drugs, or different approaches, such as surgical procedures and drug therapy. The comparison may focus only on the relative medical benefits and risks of the different options or it may weigh both their costs and their benefits. [The methods of comparative effectiveness research](#) (Annu Rev Public Health 2012; 33: 425-45) defines the key elements of CER as (a) head-to-head comparison of active treatments, (b) study populations typical of day-to-day clinical practice, and (c) a focus on evidence to inform health care tailored to the characteristics of individual patients. In [What is Comparative Effectiveness Research](#), the AHRQ highlights that CER requires the development, expansion and use of a variety of data sources and methods to conduct timely and relevant research and disseminate the results in a form that is quickly usable. The evidence may come from a review and synthesis of available evidence from existing clinical trials or observational studies or from the conduct of studies that generate new evidence. In [Developing a Protocol for Observational Comparative Effectiveness Research: A User's Guide, AHRQ](#) also highlights that CER is still a relatively new field of enquiry that has its origin across multiple disciplines and is likely to evolve and be refined over time.

Among resources for keeping up with the evolution in this field, the US National Library of Medicine provides a web site for [queries on CER](#).

The terminology 'Relative effectiveness assessment (REA)' is also used when comparing multiple technologies or a new technology against standard of care, while 'rapid' REA refers to performing an assessment within a limited timeframe in the case of a new marketing authorisation or a new indication granted for an approved medicine ([What is a rapid review? A methodological exploration of rapid reviews in Health Technology Assessments](#). Int J Evid Based Healthc. 2012; 10(4): 397-410).

10.1.2. General aspects

Several initiatives have promoted the conduct of CER and REA and proposed general methodological guidance to help in the design and analysis of such studies.

The [Methodological Guidelines for Rapid Relative Effectiveness Assessment of Pharmaceuticals](#) developed by [EUnetHTA](#) cover a broad spectrum of issues on REA. They address methodological challenges that are encountered by health technology assessors while performing rapid REA and provide and discuss practical recommendations on definitions to be used and how to extract, assess and present relevant information in assessment reports. Specific topics covered include the choice of comparators, strengths and limitations of various data sources and methods, internal and external validity of studies, the selection and assessment of endpoints (including composite and surrogate endpoints and Health Related Quality of Life [HRQoL]) and the evaluation of relative safety.

AHRQ's [Developing a Protocol for Observational Comparative Effectiveness Research: A User's Guide](#) identifies minimal standards and best practices for observational CER. It provides principles on a wide range of topics for designing research and developing protocols, with relevant questions to be addressed and checklists of key elements to be considered. The [GRACE Principles](#) provide guidance on the evaluation of the quality of observational CER studies to help decision-makers in recognizing high-quality studies and researchers in design and conduct high quality studies. A checklist to evaluate the quality of observational CER studies is also provided. [The International Society for Pharmacoeconomics and Outcomes Research \(ISPOR\)](#) addressed several key issues of CER in three publications: [Part I](#) includes the selection of study design and data sources and the reporting and interpretation of results in the light of policy questions; [Part II](#) relates to the validity and generalisability of study results, with an overview of potential threats to validity; [Part III](#) includes approaches to reducing such threats and, in particular, to controlling of confounding. The [Patient Centered Outcomes Research Institute \(PCORI\)](#) Methodology Standards document provides standards for patient-centred outcome research that aims to improve the way research questions are selected, formulated and addressed, and findings reported. The PCORI group has recently published how stakeholders may be involved in PCORI research, [Stakeholder-Driven Comparative Effectiveness Research](#) (JAMA 2015; 314: 2235-2236). In a [Journal of Clinical Epidemiology series of articles](#), the [Grading of Recommendations Assessment, Development, and Evaluation \(GRADE\) working group](#) offers a structured process for rating quality of evidence and grading strength of recommendations in systematic reviews, health technology assessment and clinical practice guidelines. The GRADE group recommends individuals new to GRADE to first read the [6-part 2008 BMJ series](#).

A guideline on methods for performing systematic reviews of existing comparative effectiveness research has been published by the AHRQ ([Methods Guide for Effectiveness and Comparative Effectiveness Reviews](#)).

The [RWE Navigator website](#) has been developed by the IMI GetReal consortium to provide recommendations on the use of real-world evidence for decision-making on effectiveness and relative effectiveness of medicinal products. It discusses important topics such as the sources of real-world data, study designs, approaches to summarising and synthesising the evidence, modelling of effectiveness and methods to adjust for bias and governance aspects. It also presents a glossary of terms and case studies relevant for RWD research, with a focus on effectiveness research.

10.1.3. Prominent issues in CER

10.1.3.1. Randomised clinical trials vs. observational studies

While RCTs are considered to provide the most robust evidence of the efficacy of therapeutic options, they are affected by well-recognised qualitative and quantitative limitations that may not reflect how the drug of interest will perform in real-life. Moreover, relatively few RCTs are traditionally designed using an alternative therapeutic strategy as a comparator, which limits the utility of the resulting data in establishing recommendations for treatment choices. For these reasons, other research methodologies such as pragmatic trials and observational studies may complement traditional explanatory RCTs in CER.

[Explanatory and Pragmatic Attitudes in Therapeutic Trials](#) (J Chron Dis 1967; republished in J Clin Epidemiol. 2009;62(5):499-505) distinguishes between two approaches in designing clinical trials: the 'explanatory' approach, which seeks to understand differences between the effects of treatments administered in experimental conditions, and the 'pragmatic' approach which seeks to answer the practical question of choosing the best treatment administered in normal conditions of use. The two approaches affect the definition of the treatments, the assessment of results, the choice of subjects and the way in which the treatments are compared. [A pragmatic-explanatory continuum indicator summary \(PRECIS\): a tool to help trial designers](#) (CMAJ 2009; 180 (10):E47-57) quantifies distinguishing characteristics between pragmatic and explanatory trials and has been updated in [The Precis-2 tool: designing trials that are fit for purpose](#) (BMJ 2015; 350: h2147). A checklist of eight items for the reporting of pragmatic trials was also developed as an extension of the CONSORT statement to facilitate the use of results from such trials in decisions about health-care ([Improving the reporting of pragmatic trials: an extension of the CONSORT statement](#). BMJ 2008;337 (a2390):1-8).

The article [Why we need observational studies to evaluate effectiveness of health care](#) (BMJ 1996;312(7040):1215-18) documents situations in the field of health care intervention assessment where observational studies are needed because randomised trials are either unnecessary, inappropriate, impossible or inadequate. In a review of five interventions, [Randomized, controlled trials, observational studies, and the hierarchy of research designs](#) (N Engl J Med 2000;342(25):1887-92) found that the results of well-designed observational studies (with either a cohort or case-control design) did not systematically overestimate the magnitude of treatment effects. [In defense of Pharmacoepidemiology-Embracing the Yin and Yang of Drug Research](#) (N Engl J Med 2007;357(22):2219-21) shows that strengths and weaknesses of RCTs and observational studies make both designs necessary in the study of drug effects. However, [When are observational studies as credible as randomised trials](#) (Lancet 2004; 363(9422):1728-31) explains that observational studies are suitable for the study of adverse (non-predictable) effects of drugs but should not be used for intended effects of drugs because of the potential for selection bias.

With regard to the selection and assessment of endpoints for CER, the [COMET \(Core Outcome Measures in Effectiveness Trials\)](#) Initiative aims at developing agreed minimum standardized sets of outcomes ('core outcome sets', COS) to be assessed and reported in effectiveness trials of a

specific condition as discussed in [Choosing Important Health Outcomes for Comparative Effectiveness Research: An Updated Review and User Survey](#) (PLoS One. 2016 ;11(1):e0146444.).

10.1.3.2. Use of electronic healthcare databases

[A review of uses of health care utilization databases for epidemiologic research on therapeutics](#) (J Clin Epidemiol. 2005;58(4):323-37) considers the application of health care utilisation databases to epidemiology and health services research, with particular reference to the study of medications. Information on relevant covariates and in particular on confounding factors may not be available or adequately measured in electronic healthcare databases. To overcome this limit, CER studies have integrated information from health databases with information collected ad hoc from study subjects. [Enhancing electronic health record measurement of depression severity and suicide ideation: a Distributed Ambulatory Research in Therapeutics Network \(DARTNet\) study](#) (J Am Board Fam Med. 2012;25(5):582-93) shows the value of adding direct measurements and pharmacy claims data to data from electronic healthcare records participating in [DARTNet](#). [Assessing medication exposures and outcomes in the frail elderly: assessing research challenges in nursing home pharmacotherapy](#) (Med Care 2010;48(6 Suppl):S23-31) describe how merging longitudinal electronic clinical and functional data from nursing home sources with Medicare and Medicaid claims data can support unique study designs in CER but pose many challenging design and analytic issues. [Pragmatic randomized trials using routine electronic health records: putting them to the test](#) (BMJ 2012;344:e55) discusses opportunities for using electronic healthcare records for conducting pragmatic trials.

A model based on counterfactual theory for CER using large administrative healthcare databases has been suggested, in which causal inference from observational studies based on large administrative health databases is viewed as an emulation of a randomized trial. This 'target trial' is made explicit and design and analytic approaches are reviewed in [Using Big Data to Emulate a Target Trial When a Randomized Trial Is Not Available](#) (Am J Epidemiol (2016) 183 (8): 758-764).

10.1.3.3. Bias and confounding in observational CER

Methodological issues and principles of Section 5 of the ENCePP Guide are applicable to CER as well and the textbooks cited in that chapter are recommended for consultation.

[Methods to assess intended effects of drug treatment in observational studies are reviewed](#) (J Clin Epidemiol 2004;57(12):1223-31) provides an overview of methods that seek to adjust for confounding in observational studies when assessing intended drug effects. [Developments in post-marketing comparative effectiveness research](#) (Clin Pharmacol Ther 2007;82(2):143-56) also reviews the roles of propensity scores (PS), instrumental variables and sensitivity analyses to reduce measured and unmeasured confounding in CER. Use of propensity scores and disease risk scores in the context of observational health-care programme research is described in [Summary Variables in Observational Research: Propensity Scores and Disease Risk Scores](#). More recently, high-dimensional propensity score has been suggested as a method to further improve control for confounding as these variables may collectively be proxies for unobserved factors. Results presented in [High-dimensional propensity score adjustment in studies of treatment effects using health care claims data](#) (Epidemiology 2009;20(4):512-22) show that in a selected empirical evaluation, high-dimensional propensity score improved confounding control compared to conventional PS adjustment when benchmarked against results from randomized controlled trials. See section 5.3.4 of the Guide for an in-depth discussion of propensity scores. Several methods can be considered to handle cofounders in non-experimental CER ([Confounding adjustment in comparative effectiveness research conducted within distributed research networks](#) (Med Care 2013 ; 51 : S4-S10); [Disease Risk Score \(DRS\) AS A Confounder Summary Method; Systematic Review and Recommendations](#) (Pharmacoepidemiol Drug Saf 2013; 22: 122–129). [Strategies for](#)

[selecting variables for adjustment in non-experimental CER](#) have also been proposed (Pharmacoepidemiol Drug Saf 2013; 22: 1139–1145).

A reason for discrepancies between results of randomised trials and observational studies may be the use of prevalent drug users in the latter. [Evaluating medication effects outside of clinical trials: new-user designs](#) (Am J Epidemiol. 2003; 158(9):915-20) explains the biases introduced by use of prevalent drug users and how a new-user (or incident user) design eliminate these biases by restricting analyses to persons under observation at the start of the current course of treatment. [The Incident User Design in Comparative Effectiveness Research](#) reviews published CER case studies in which investigators had used the incident user design, discusses its strengths (reduced bias) and weakness (reduced precision of comparative effectiveness estimates) and provides recommendations to investigators considering to use this design. [The value of incident user design and exceptions has been reviewed](#) (Pharmacoepidemiol Drug Saf 2013; 22: 1–6).

10.2. Vaccine safety and effectiveness

10.2.1. Vaccine safety

10.2.1.1. General aspects

Specific aspects of vaccines to be considered in pharmacovigilance and pharmacoepidemiology have been highlighted in several documents. The [Report of the CIOMS/WHO Working Group on Definition and Application of Terms for Vaccine Pharmacovigilance](#) (2012) emphasises that characteristics of the vaccine and the vaccinated population, settings and circumstances of vaccine administration and data analysis issues are worthy of special attention during vaccine safety monitoring. It also provides definitions and explanatory notes for the terms ‘vaccine pharmacovigilance’, ‘vaccination failure’ and ‘adverse event following immunisation (AEFI)’. Recommendations on vaccine-specific aspects of the EU pharmacovigilance system, including on risk management, signal detection and post-authorisation safety studies (PASS) are presented in the [Module P.I: Vaccines for prophylaxis against infectious diseases](#) of the Good pharmacovigilance practices (GVP).

Methods for vaccine pharmacovigilance have been developed by the [Brighton Collaboration](#), which provides [resources](#) to facilitate and harmonise collection, analysis and presentation of vaccine safety data, including case definitions, an electronic tool to help the classification of reported signs and symptoms, template protocols and guidelines. The [CIOMS Guide to Active Vaccine Safety Surveillance](#) (2017) describes the process of determining whether active vaccine safety surveillance is necessary, more specifically in the context of resource-limited countries, and, if so, of choosing the best type of active safety surveillance and considering key implementation issues. [Module 4 \(Surveillance\)](#) of the e-learning training course [Vaccine Safety Basics](#) of the World Health Organization (WHO) describes pharmacovigilance principles, causality assessment procedures, surveillance systems and factors influencing the risk-benefit balance of vaccines. In particular, in contrast to the use of other medicines, vaccines are often used in healthy people and it is not only important to identify possible risks but also to emphasize safety if it does exist. For example a systematic review on influenza vaccination in pregnancy and the risk of congenital anomalies in newborns did not find an association, adding to the evidence base of influenza vaccination in pregnancy ([Maternal Influenza Vaccination and Risk for Congenital Malformations: A Systematic Review and Meta-analysis](#). Obstet Gynecol 2015; 126(5):1075-84.).

10.2.1.2. Signal detection for vaccines

The GVP [Module P.I: Vaccines for prophylaxis against infectious diseases](#) describes issues to be considered when applying methods for disproportionality analyses for vaccines, including the choice

of the comparator group and the use of stratification. [Effects of stratification on data mining in the US Vaccine Adverse Event Reporting System \(VAERS\)](#) (Drug Saf 2008; 31(8):667-74) demonstrates that stratification can reveal and reduce confounding and unmask some vaccine-event pairs not found by crude analyses. However, [Stratification for Spontaneous Report Databases](#) (Drug Saf 2008; 31(11):1049-52) highlights that extensive use of stratification in signal detection algorithms should be avoided as it can mask true signals. [Vaccine-Based Subgroup Analysis in VigiBase: Effect on Sensitivity in Paediatric Signal Detection](#) (Drug Saf 2012; 35(4):335-346) further examines the effects of subgroup analyses based on the relative distribution of vaccine/non-vaccine reports in paediatric ADR data.

The article [Optimization of a quantitative signal detection algorithm for spontaneous reports of adverse events post immunization](#) (Pharmacoepidemiology and drug safety 2013; 22: 477–487) explores various ways of improving performance of signal detection algorithms when looking for vaccines.

The article [Adverse events associated with pandemic influenza vaccines: comparison of the results of a follow-up study with those coming from spontaneous reporting](#) (Vaccine 2011; 29(3):519-22) reported a more complete pattern of reactions when using two complementary methods for first characterisation of the post-marketing safety profile of a new vaccine, which may impact on signal detection.

10.2.1.3. Signal refinement

When prompt decision-making about a safety concern is required and there is insufficient time to review individual cases, the GVP [Module P.I: Vaccines for prophylaxis against infectious diseases](#) suggests the conduct of observed vs. expected (O/E) analyses for signal validation and preliminary signal evaluation. The module discusses key requirements of O/E analyses: the observed number of cases detected in a passive or active surveillance systems, near real-time exposure data, appropriately stratified background incidence rates (to calculate the expected number of cases) and sensitivity analyses around these measures.

[Human papilloma virus immunization in adolescents and young adults: a cohort study to illustrate what events might be mistaken for adverse reactions](#) (Pediatr Infect Dis J 2007; 26(11):979-84) and [Health problems most commonly diagnosed among young female patients during visits to general practitioners and gynecologists in France before the initiation of the human papillomavirus vaccination program](#) (Pharmacoepidemiol Drug Saf 2012; 21(3):261-80) illustrate the importance of collecting background rates by estimating risks of coincident associations of emergency consultations, hospitalisations and outpatients consultations with vaccination. Rates of selected disease events for several countries also vary by age, sex, method of ascertainment and geography, as shown in [Importance of background rates of disease in assessment of vaccine safety during mass immunisation with pandemic H1N1 influenza vaccines](#) (Lancet 2009; 374(9707):2115-22). Moreover, [Guillain-Barré syndrome and influenza vaccines: A meta-analysis](#) (Vaccine 2015; 33(31):3773-8) suggests that a trend observed between different geographical areas would be consistent with a different susceptibility of developing a particular adverse reaction among different populations.

Simple 'snapshot' O/E analyses are easy to perform but may not be appropriate for continuous monitoring due to inflation of type 1 error rates when multiple tests are performed. [Safety monitoring of Influenza A/H1N1 pandemic vaccines in EudraVigilance](#) (Vaccine 2011; 29(26):4378-87) illustrates that simple 'snapshot' O/E analyses are also affected by uncertainties regarding the numbers of vaccinated individuals and age-specific background incidence rates.

Sequential methods, as described in [Early detection of adverse drug events within population-based health networks: application of sequential methods](#) (Pharmacoepidemiol Drug Saf 2007;

16(12):1275-1284), allow O/E analyses to be performed on a routine (e.g. weekly) basis using cumulative data with adjustment for multiplicity. Such methods are routinely used for near-real time surveillance in the [Vaccine Safety Datalink \(VSD\)](#) ([Near real-time surveillance for influenza vaccine safety: proof-of-concept in the Vaccine Safety Datalink Project](#). Am J Epidemiol 2010;171(2):177-88). Potential issues are described in [Challenges in the design and analysis of sequentially monitored postmarket safety surveillance evaluations using electronic observational health care data](#) (Pharmacoepidemiol Drug Saf 2012; 21(S1):62-71). A review of signals detected over 3 years with these methods in Vaccine Safety Datalink concluded that care with data quality, outcome definitions, comparison groups and length of surveillance is required to enable detection of true safety problems while controlling error rates ([Active surveillance for adverse events: the experience of the Vaccine Safety Datalink Project](#) (Pediatrics 2011; 127(S1):S54-S64). Sequential methods are, therefore, more robust but also more complex to perform, understand and communicate to a non-statistical audience.

[A new self-controlled case series method for analyzing spontaneous reports of adverse events after vaccination](#) (Am J Epidemiol 2013;178(9):1496-504) extends the self-controlled case series approach to explore and quantify vaccine safety signals from spontaneous reports. It uses parametric and nonparametric versions with different assumptions to account for the specific features of the data (e.g., large amount of underreporting and variation of reporting with time since vaccination). The method should be seen as a signal strengthening approach for quickly exploring a signal based on spontaneous reports prior to a pharmacoepidemiologic study, if any. The method was used to document the risk of intussusception after rotavirus vaccines (see [Intussusception after Rotavirus Vaccination — Spontaneous Reports](#); N Engl J Med 2011; 365:2139).

10.2.1.4. Hypothesis testing studies

Traditional study designs such as cohort and case-control studies may be difficult to implement for vaccines where studies involve populations with high vaccine coverage rates, an appropriate unvaccinated group is lacking or adequate information on covariates at the individual level is not available. Frequent sources of confounding to be considered are socioeconomic status, underlying health status and other factors influencing the probability of being vaccinated. [Control without separate controls: evaluation of vaccine safety using case-only methods](#) (Vaccine 2004; 22(15-16):2064-70) describes and illustrates epidemiological methods that are useful in such situations. They are mostly case-only design described in section 5.3.2 of the Guide.:

- The case-crossover design was primarily developed to investigate the association between a vaccine and an adverse event. In this design, control information for each case is based on own past exposure experience and a person can 'crossover' between two or more exposure levels. It is a retrospective design that requires the strong assumption that the underlying probability of vaccination should be the same in all defined time intervals, but this is unlikely to hold for paediatric vaccines administered according to strict schedules or for seasonally administered vaccines.
- The self-controlled case series (SCCS) design can be both prospective and retrospective and aims to estimate a relative incidence, which compares the incidence of adverse events within periods of hypothesised excess risk due to exposure with incidence during all other times.
- The case-coverage design uses exposure information on cases and population data on vaccination coverage to serve as control. It requires reliable and detailed vaccine coverage data corresponding to the population from which cases are drawn. This will allow control of confounding by stratified analysis. During vaccine introduction, it is also particularly important to address selection bias introduced by awareness of possible occurrence of a specific outcome.

An example of a study using a case-coverage method is [Risk of narcolepsy in children and young people receiving AS03 adjuvanted pandemic A/H1N1 2009 influenza vaccine: retrospective analysis](#) (BMJ 2013; 346:f794).

The study [Control without separate controls: evaluation of vaccine safety using case-only methods](#) (Vaccine 2004; 22(15-16):2064-70) concludes that properly designed and analysed epidemiological studies using only cases, especially the SCCS method, may provide stronger evidence than large cohort studies as they control completely for fixed individual-level confounders (such as demographics, genetics and social deprivation) and typically have similar, sometimes better, power. Three factors are however critical in making optimal use of such methods: access to good data on cases, computerised vaccination records with the ability to link them to cases and availability of appropriate analysis techniques.

Several studies on vaccines have compared traditional and case-only study designs:

- [Epidemiological designs for vaccine safety assessment: methods and pitfalls](#) (Biologicals 2012; 40(5): 389-92) used three study designs (cohort, case-control and self-controlled case series) to illustrate the issues that may arise when designing an epidemiological study, such as understanding the vaccine safety question, case definition and finding, limitations of data sources, uncontrolled confounding, and pitfalls that apply to the individual designs.
- [Comparison of epidemiologic methods for active surveillance of vaccine safety](#) (Vaccine 2008; 26(26): 3341-3345) performed a simulation study to compare four designs (matched-cohort, vaccinated-only (risk interval) cohort, case-control and self-controlled case series) in the context of vaccine safety surveillance. The cohort study design allowed for the most rapid signal detection, the least false-positive error and highest statistical power in performing sequential analysis. The authors highlight, however, that the chief limitation of this simulation is the exclusion of confounding effects and the lack of chart review, which is a time and resource intensive requirement.
- Another simulation study ([Four different study designs to evaluate vaccine safety were equally validated with contrasting limitations](#). J Clin Epidemiol 2006; 59(8):808-818) compared four study designs (cohort, case-control, risk-interval and SCCS) with the conclusion that all the methods were valid designs, with contrasting strengths and weaknesses. The SCCS method, in particular, proved to be an efficient and valid alternative to the cohort method.
- [Hepatitis B vaccination and first central nervous system demyelinating events: Reanalysis of a case-control study using the self-controlled case series method](#). Vaccine 2007; 25(31): 5938-43) describes how the SCCS found similar results as the case-control study but with greater precision as it used cases without matched controls excluded from the case-control analysis. This is at the cost of the assumption that exposures are independent of earlier events. The authors recommended that, if case-control studies of vaccination and adverse events are undertaken, parallel case-series analyses should also be conducted, where appropriate.

In situations where primary data collection is needed (e.g. a pandemic), the SCCS may not be timely since follow-up time needs to be accrued. In such instances, the Self-controlled Risk Interval (SCRI) method can be used to shorten the observation time (see [The risk of Guillain-Barre Syndrome associated with influenza A \(H1N1\) 2009 monovalent vaccine and 2009-2010 seasonal influenza vaccines: Results from self-controlled analyses](#). Pharmacoepidemiol Drug Safety 2012; 21(5): 546-52), historical background rates can be used for an O/E analysis (see [Near real-time surveillance for influenza vaccine safety: proof-of-concept in the Vaccine Safety Datalink Project](#). Am J Epidemiol 2010; 171(2): 177-88) or a classical case-control study can be performed, as used in [Guillain-Barré syndrome and adjuvanted pandemic influenza A \(H1N1\) 2009 vaccine: multinational case-control study in Europe](#). BMJ 2011; 343: d3908).

Ecological analyses should not be considered hypothesis testing studies. See section 5.5. of this Guide.

10.2.1.5. Meta-analyses

[A systematic review evaluating the potential for bias and the methodological quality of meta-analyses in vaccinology](#) (Vaccine 2007; 25(52):8794-806) provides a comprehensive overview of the methodological quality and limitations of 121 meta-analyses of vaccine studies. [Association between Guillain-Barré syndrome and influenza A \(H1N1\) 2009 monovalent inactivated vaccines in the USA: a meta-analysis](#) (Lancet 2013; 381(9876):1461-8) describes a self-controlled risk-interval design in a meta-analysis of six studies at the patient level with a reclassification of cases according to the Brighton Collaboration classification.

10.2.1.6. Studies on vaccine safety in special populations

The article [Vaccine safety in special populations](#) (Hum Vaccin 2011; 7(2):269-71) highlights common methodological issues that may arise in evaluating vaccine safety in special populations, especially infants and children who often differ in important ways from healthy individuals and change rapidly during the first few years of life, and elderly patients.

Observational studies on vaccine adverse effects during pregnancy (especially on pregnancy loss), which often use pregnancy registries or healthcare databases, are faced with three challenges: embryonic and early foetal loss are often not recognised or recorded, data on the gestational age at which these events occur are often missing, and the likelihood of vaccination increases with gestational age whereas the likelihood of foetal death decreases. [Assessing the effect of vaccine on spontaneous abortion using time-dependent covariates Cox models](#) (Pharmacoepidemiol Drug Saf 2012; 21(8):844-850) demonstrates that rates of spontaneous abortion can be severely underestimated without survival analysis techniques using time-dependent covariates to avoid immortal time bias and shows how to fit such models. [Risk of miscarriage with bivalent vaccine against human papillomavirus \(HPV\) types 16 and 18: pooled analysis of two randomised controlled trials](#) (BMJ 2010; 340:c712) explains methods to calculate rates of miscarriage, address the lack of knowledge of time of conception during which vaccination might confer risk and perform subgroup and sensitivity analyses. The [Systematic overview of data sources for drug safety in pregnancy research](#) provides an inventory of pregnancy exposure registries and alternative data sources useful to assess the safety of prenatal vaccine exposure.

Few vaccine studies are performed in immunocompromised subjects. [Influenza vaccination for immunocompromised patients: systematic review and meta-analysis by etiology](#) (J Infect Dis 2012; 206(8):1250-9) illustrates the importance of performing stratified analyses by aetiology of immunocompromise and possible limitations due to residual confounding, differences within and between etiological groups and small sample size in some etiological groups. Further research is needed on this topic.

10.2.2. Vaccine effectiveness

10.2.2.1. Definitions

[Vaccine effects and impact of vaccination programmes in post-licensure studies](#) (Vaccine 2013; 31(48):5634-42) reviews and delineates, among the various evaluations of vaccine intervention, what applies to the effectiveness of vaccine and to the impact of vaccination programmes, proposes epidemiological measures of public health impact, describes relevant methods to measure these effects and discusses the assumptions and potential biases involved.

10.2.2.2. Traditional cohort and case-control studies

Generic protocols for [retrospective case-control studies](#) and [retrospective cohort studies](#) to assess the effectiveness of rotavirus vaccination in EU Member States based on computerised databases were published by the European Centre for Disease Prevention and Control ([ECDC](#)). They describe the information that should be collected by country and region in vaccine effectiveness studies and the data sources that may be available to identify virus-related outcomes a vaccine is intended to avert, including hospital registers, computerised primary care databases, specific surveillance systems (i.e. laboratory surveillance, hospital surveillance, primary care surveillance) and laboratory registers. Based on a meta-analysis comprising 49 cohort studies and 10 case-control studies, [Efficacy and effectiveness of influenza vaccines in elderly people: a systematic review](#) (Lancet 2005;366(9492):1165-74) highlights the heterogeneity of outcomes and study populations included in such studies and the high likelihood of selection bias.

Non-specific effects of vaccines, such as a decrease of mortality, have been claimed in observational studies but generally can be affected by bias and confounding. [Data collection in observational studies](#) (Trop Med Int Health 2009;14(9):969-76.) and [Methodological issues in the design and analysis of cohort studies](#) (Trop Med Int Health 2009;14(9):977-85) provide recommendations for vaccine observational studies conducted in countries with high mortality; these recommendations have wider relevance.

10.2.2.3. Screening method

The screening method estimates vaccine effectiveness by comparing vaccination coverage in positive cases of a disease (e.g. influenza) with the vaccination coverage in the population from which the cases are derived (e.g., the same age group). If representative data on cases and vaccination coverage are available, it can provide an inexpensive and ready-to-use method that can be useful in providing early effectiveness estimates or identify changes in effectiveness over time. However, [Application of the screening method to monitor influenza vaccine effectiveness among the elderly in Germany](#) (BMC Infect Dis. 2015;15(1):137) emphasises that accurate and age-specific vaccine coverage rates are crucial to provide valid VE estimates. Since adjusting for important confounders and the assessment of product-specific VE is generally not possible, this method should be considered only a supplementary tool for assessing crude VE.

10.2.2.4. Indirect cohort (Broome) method

The indirect cohort method is a case-control type design which uses cases caused by non-vaccine serotypes as controls. [Use of surveillance data to estimate the effectiveness of the 7-valent conjugate pneumococcal vaccine in children less than 5 years of age over a 9 year period](#) (Vaccine 2012;30(27):4067-72) applied this method to evaluate the effectiveness of a pneumococcal conjugate vaccine against invasive pneumococcal disease (IPD) and compared the results to the effectiveness measured using a standard case-control study conducted during the same time period. The authors considered the method would be most useful shortly after vaccine introduction, and less useful in a setting of very high vaccine coverage and fewer vaccine-type cases. [Using the Indirect Cohort Design to Estimate the Effectiveness of the Seven Valent Pneumococcal Conjugate Vaccine in England and Wales](#) (PLoS ONE 6(12):e28435. doi:10.1371/journal.pone.0028435) describes how the method was used to estimate effectiveness of various numbers of doses as well as for each vaccine serotype.

10.2.2.5. Density case-control design

[Effectiveness of live-attenuated Japanese encephalitis vaccine \(SA14-14-2\): a case-control study](#) (Lancet 1996;347(9015):1583-6) describes a case control study of incident cases in which the

control group consisted of all village-matched children of a given age who were at risk of developing disease at the time that the case occurred (density sampling). The effect measured is an incidence density rate ratio.

10.2.2.6. Test negative design

The article [The test-negative design for estimating influenza vaccine effectiveness](#) (Vaccine 2013;31(17):2165-8) explains the rationale, assumptions and analysis of the test-negative study as applied to influenza VE. Study subjects are all persons who seek care for an acute respiratory illness and influenza VE is estimated from the ratio of the odds of vaccination among subjects testing positive for influenza to the odds of vaccination among subject testing negative. This design is less susceptible to bias due to misclassification of infection and the confounding by health care-seeking behaviour, at the cost of difficult-to-test assumptions.

[Effectiveness of rotavirus vaccines in preventing cases and hospitalizations due to rotavirus gastroenteritis in Navarre, Spain](#) (Vaccine 2012; 30(3):539-43) evaluates effectiveness using a test negative case-control design based on electronic clinical reports. Cases were children with confirmed rotavirus and controls were those who tested negative for rotavirus in all samples. The test-negative design was based on an assumption that the rate of gastroenteritis caused by pathogens other than rotavirus is the same in both vaccinated and unvaccinated persons. This approach may rule out differences in parental attitude when seeking medical care and of physician differences in making decisions about stool sampling or hospitalisation. A limitation is sensitivity of antigen detection which may underestimate vaccine effectiveness. In addition, if virus serotype is not available, it is not possible to study the association between vaccine failure and a possible mismatch of vaccine strains and circulating strains of virus.

The article [2012/13 influenza vaccine effectiveness against hospitalised influenza A\(H1N1\)pdm09, A\(H3N2\) and B: estimates from a European network of hospitals](#) (EuroSurveill 2015;20(2):pii=21011) illustrates a multicentre test-negative case-control study to estimate influenza VE in 18 hospitals. It is believed that confounding due to health-seeking behaviour is minimised since, in the study sites, all people needing hospitalisation are likely to be hospitalised. The study [Trivalent inactivated seasonal influenza vaccine effectiveness for the prevention of laboratory-confirmed influenza in a Scottish population 2000 to 2009](#) (EuroSurveill 2015;20(8):pii=21043) applied this method using a Scotland-wide linkage of patient-level primary care, hospital and virological swab data over nine influenza seasons and discusses strengths and weaknesses of the design in this context.

10.2.2.7. Case coverage design

This design is described in section 10.2.1.4.

10.2.2.8. Impact assessment

A generic study protocol to assess [the impact of rotavirus vaccination](#) in EU Member States has been published by the ECDC. It recommends the information that needs to be collected to compare the incidence/proportion of rotavirus cases in the period before and after the introduction of the vaccine. These generic protocols need to be adapted to each country/regions and specific situation.

The impact of vaccination can be quantified in children in the age group targeted for the vaccine (overall effect) or in children of other age groups (indirect effect). The direct effect of a vaccine, however, needs to be defined by the protection it confers given a specific amount of exposure to infection and not just a comparable exposure. [Direct and indirect effects in vaccine efficacy and effectiveness](#) (Am J Epidemiol 1991; 133(4):323-31) describes how parameters intended to

measure direct effects must be robust and interpretable in the midst of complex indirect effects of vaccine intervention programmes.

[Impact of rotavirus vaccination in regions with low and moderate vaccine uptake in Germany](#) (Hum Vaccin Immunother 2012; 8(10):1407-15) describes an impact assessment of rotavirus vaccination comparing the incidence rates of hospitalisations before, and in seasons after, vaccine introduction using data from national mandatory disease reporting system.

[First year experience of rotavirus immunisation programme in Finland](#) (Vaccine 2012; 31(1):176-82) estimates the impact of a rotavirus immunisation programme on the total hospital inpatient and outpatient treated acute gastroenteritis burden and on severe rotavirus disease burden during the first year after introduction. The study may be considered as a vaccine-probe-study, where unspecific disease burden prevented by immunisation is assumed to be caused by the agent the vaccine is targeted against.

10.2.2.9. Methods to study waning immunity

The study of vaccine effectiveness against diseases where immunity wanes over time requires consideration of both the within-host dynamics of the pathogen and immune system as well as the associated population-level transmission dynamics. [Implications of vaccination and waning immunity](#) (Proc Biol Sci 2009; 276(1664):2071-80) seeks to combine immunological and epidemiological models for measles infection to examine the interplay between disease incidence, waning immunity and boosting.

10.3. Design and analysis of pharmacogenetic studies

10.3.1. Introduction

Pharmacogenetics is defined as the study of genetic variation as a determinant of drug response. It can complement information on clinical factors and disease sub-phenotypes to optimise the prediction of treatment response.

Individual variation in the response to drugs is an important clinical issue and may range from a lack of therapeutic effect to serious adverse drug reactions. This heterogeneity of response has important policy implications if individual patients not responding to conventional agents are denied access to other agents based on clinical trial evidence and systematic reviews that show no overall benefit. While clinical variables such as disease severity, age, concomitant drug use and illnesses are potentially important determinants of the response to drugs, heterogeneity in drug disposition (absorption, metabolism, distribution, and excretion) and targets (such as receptors and signal transduction modulators) may be an important cause of inter-individual variability in the therapeutic effects of drugs (see [Pharmacogenomics: translating functional genomics into rational therapeutics](#). Science 1999;286(5439):487-91). Identification of variation in genes which modify the response to drugs provides the opportunity to optimise safety and effectiveness of the currently available drugs and develop new drugs for paediatric and adult populations (see [Drug discovery: a historical perspective](#). Science 2000;287(5460):1960-4).

10.3.2. Identification of genetic variants

Identification of genetic variation associated with important drug or therapy-related outcomes can follow two main approaches.

The first is the candidate gene approach in which as many as dozens to thousands of genetic variations within one or several genes, including a common form of variations known as single nucleotide polymorphisms (SNPs), are genotyped, including the coding and noncoding sequence.

Generally they are chosen on the grounds of biological plausibility, which may have been proven before in previous studies, or of knowledge of functional genes known to be involved in pharmacokinetic and pharmacodynamics pathways or related to the disease or intermediate phenotype. [Methodological and statistical issues in pharmacogenomics](#) (J Pharm Pharmacol 2010;62(2): 161-6) discusses pros and cons of a candidate gene approach and a genome-wide scan approach (see below), and [A tutorial on statistical methods for population association studies](#) (Nat Rev Genet 2006;7(10): 781-91) gives an outline of key methods that can be used. The advantage of the candidate gene approach is that resources can be directed to several important genetic polymorphisms and the higher a priori chance of relevant drug-gene interactions. This approach, however, requires a priori information about the likelihood of the polymorphism, gene, or gene-product interacting with a drug or drug pathway. [Moving towards individualized medicine with pharmacogenomics](#) (Nature 2004;429:464-8) explains that lack or incompleteness of information on genes from previous studies may result in the failure in identifying every important genetic determinant in the genome.

The second approach is hypothesis-generating or hypothesis-agnostic, known as genome-wide, which identifies genetic variants across the whole genome. By comparing the frequency of genetic or SNP markers between drug responders and non-responders, or those with or without drug toxicity, important genetic determinants are identified. In this approach, no previous information or specific gene/variant hypothesis is needed. Because of the concept of linkage disequilibrium, whereby certain genetic determinants tend to be co-inherited together, it is possible that the genetic associations identified through a genome-wide approach may not be truly biologically functional polymorphisms, but instead may simply be a linkage-related marker of another genetic determinant that is the true biologically relevant genetic determinant. Thus, this approach is considered discovery in nature. It may detect the SNPs in genes, which were previously not considered as candidate genes, or even SNPs outside of the genes. Nonetheless, failure to cover all relevant genetic risk factors can still be a problem, though less than with the candidate gene approach. It is therefore important to conduct replication and validation studies (in vivo and in vitro) to ascertain the generalisability of findings to populations of patients, to characterise the mechanistic basis of the effect of these genes on drug action, and to identify true biologic genetic determinants. This approach is useful for studying complex diseases where multiple genetic variations contribute to disease risk, but are applicable to disease and treatment outcomes.

Various genome-wide approaches are currently available including genome and exome sequencing, and application of various chips that type hundreds of thousands to billions of SNPs (e.g. exome chip). Finally, power is usually limited to detect only common variants with a large effect, and therefore large sample sizes should be considered, e.g. through pooling of biobanks.

10.3.3. Study designs

Several options are available for the design of pharmacogenetic studies. Firstly, RCTs, both pre- and post-authorisation, provide the opportunity to address several pharmacogenetic questions. [Pharmacogenetics in randomized controlled trials: considerations for trial design](#) (Pharmacogenomics 2011;12(10): 1485-92) describes three different trial designs differing in the timing of randomization and genotyping, and [Promises and challenges of pharmacogenetics: an overview of study design, methodological and statistical issues](#) (JRSM Cardiovasc Dis 2012 5;1(1)) discusses outstanding methodological and statistical issues that may lead to heterogeneity among reported pharmacogenetic studies and how they may be addressed. Pharmacogenetic trials can be designed (or post hoc analysed) with the intention to study whether a subgroup of patients, defined by certain genetic characteristics, respond differently to the treatment under study. Alternatively, a trial can verify whether genotype-guided treatment is beneficial over standard care. Obvious limitations with regard to the assessment of rare adverse drug events are the large sample

size required and its related high costs. In order to make a trial as efficient as possible in terms of time, money and/or sample size, it is possible to opt for an adaptive trial design, which allows prospectively planned modifications in design after patients have been enrolled in the study. Such a design uses accumulating data to decide how to modify aspects of the study during its progress, without undermining the validity and integrity of the trial. An additional benefit is that the expected number of patients exposed to an inferior/harmful treatment can be reduced (see [Potential of adaptive clinical trial designs in pharmacogenetic research](#). *Pharmacogenomics* 2012; 13(5): 571-8).

Observational studies are the alternative and can be family-based (using twins or siblings) or population-based (using unrelated individuals). The main advantage of family-based studies is the avoidance of bias due to population stratification. A clear practical disadvantage for pharmacogenetic studies is the requirement to study families where patients have been treated with the same drugs (see [Methodological quality of pharmacogenetic studies: issues of concern](#). *Stat Med* 2008; 27(30): 6547-69).

Population-based studies may be designed to assess drug-gene interactions as cohort (including exposure-only), case-cohort and case-control studies (including case-only, as described in [Nontraditional epidemiologic approaches in the analysis of gene-environment interaction: case-control studies with no controls!](#) *Am J Epidemiol* 1996; 144(3): 207-13). Sound pharmacoepidemiological principles as described in the current Guide also apply to observational pharmacogenetic studies. A specific type of confounding due to population stratification needs to be considered in pharmacogenetic studies, and, if present, needs to be dealt with. Its presence may be obvious where the study population includes more than one immediately recognisable ethnic group; however in other studies stratification may be more subtle. Population stratification can be detected by [Pritchard and Rosenberg's method](#), which involves genotyping additional SNPs in other areas of the genome and testing for association between them and outcome. In genome-wide association studies, the data contained within the many SNPs typed can be used to assess population stratification without the need to undertake any further genotyping. Several methods have been suggested to control for population stratification such as genomic control, structure association and EIGENSTAT. These methods are discussed in [Methodological quality of pharmacogenetic studies: issues of concern](#) (*Stat Med* 2008; 27(30): 6547-69) and [Softwares and methods for estimating genetic ancestry in human populations](#) (*Hum Genomics* 2013; 7: 1).

The main advantage of exposure-only and case-only designs is the smaller sample size that is required, at the cost of not being able to study the main effects of drug exposure (case-only) or genetic variant (exposure-only) on the outcome. Furthermore, interaction can be assessed only on a multiplicative scale, whereas from a public health perspective additive interactions are very relevant. An important condition that has to be fulfilled for case-only studies is that the exposure is independent of the genetic variant, e.g. prescribers are not aware of the genotype of a patient and do not take this into account, directly or indirectly (by observing clinical characteristics associated with the genetic variant). In the exposure-only design, the genetic variant should not be associated with the outcome, for example variants of genes coding for cytochrome p-450 enzymes. When these conditions are fulfilled and the main interest is in the drug-gene interaction, these designs may be an efficient option. In practice, case-control and case-only studies usually result in the same interaction effect as empirically assessed in [Bias in the case-only design applied to studies of gene-environment and gene-gene interaction: a systematic review and meta-analysis](#) (*Int J Epidemiol* 2011; 40(5): 1329-41). The assumption of independence of genetic and exposure factors can be verified among controls before proceeding to the case-only analysis. [Further development of the case-only design for assessing gene-environment interaction: evaluation of and adjustment for bias](#) (*Int J Epidemiol* 2004; 33(5): 1014-24) conducted sensitivity analyses to describe the circumstances in which controls can be used as proxy for the source population when evaluating gene-environment independence. The gene-environment association in controls will be a

reasonably accurate reflection of that in the source population if baseline risk of disease is small (<1%) and the interaction and independent effects are moderate (i.e. risk ratio<2), or if the disease risk is low (e.g. <5%) in all strata of genotype and exposure. Furthermore, non-independence of gene-environment can be adjusted in multivariable models if non-independence can be measured in controls.

10.3.4. Data collection

The same principles and approaches to data collection as for other pharmacoepidemiological studies can be followed (see section 3 of this Guide on Approaches to Data Collection). An efficient approach to data collection for pharmacogenetic studies is to combine secondary use of electronic health records with primary data collection (e.g. biological samples to extract DNA).

Examples are given by [SLCO1B1 genetic variant associated with statin-induced myopathy: a proof-of-concept study using the clinical practice research datalink](#) (Clin Pharmacol Ther 2013;94(6):695-701), [Diuretic therapy, the alpha-adducin gene variant, and the risk of myocardial infarction or stroke in persons with treated hypertension](#) (JAMA 2002;287(13):1680-9) and [Interaction between the Gly460Trp alpha-adducin gene variant and diuretics on the risk of myocardial infarction](#) (J Hypertens 2009 Jan;27(1):61-8). Another approach to enrich electronic health records with biological samples is record linkage to biobanks as illustrated in [Genetic variation in the renin-angiotensin system modifies the beneficial effects of ACE inhibitors on the risk of diabetes mellitus among hypertensives](#) (Hum Hypertens 2008;22(11):774-80). A third approach is to use active surveillance methods to fully characterise drug effects such that a rigorous phenotype can be developed prior to genetic analysis. This approach was followed in [Adverse drug reaction active surveillance: developing a national network in Canada's children's hospitals](#) (Pharmacoepidemiol Drug Saf 2009;18(8):713-21) and [EUDRAGENE: European collaboration to establish a case-control DNA collection for studying the genetic basis of adverse drug reactions](#) (Pharmacogenomics 2006;7(4):633-8).

10.3.5. Data analysis

The focus of data analysis should be on the measure of effect modification (see section 4.2.4 of this Guide on Effect Modification). Attention should be given to whether the mode of inheritance (e.g. dominant, recessive or additive) is defined a priori based on prior knowledge from functional studies. However, investigators are usually naïve regarding the underlying mode of inheritance. A solution might be to undertake several analyses, each under a different assumption, though the approach to analysing data raises the problem of multiple testing (see [Methodological quality of pharmacogenetic studies: issues of concern](#). Stat Med 2008;27(30):6547-69). The problem of multiple testing and the increased risk of type I error is in general a problem in pharmacogenetic studies evaluating multiple SNPs, multiple exposures and multiple interactions. The most common approach to correct for multiple testing is to use the Bonferroni correction. This correction may be considered too conservative and runs the risk of producing many pharmacogenetic studies with a null result. Other approaches to adjust for multiple testing include permutation testing and false discovery rate (FDR) control, which are less conservative. The FDR, described in [Statistical significance for genomewide studies](#) (Proc Natl Acad Sci USA 2003;100(16):9440-5), estimates the expected proportion of false-positives among associations that are declared significant, which is expressed as a q-value.

Alternative innovative methods are under development and may be used in the future, such as the systems biology approach, a Bayesian approach, or data mining (see [Methodological and statistical issues in pharmacogenomics](#). J Pharm Pharmacol 2010;62(2):161-6).

Important complementary approaches include the conduct of individual patient data meta-analyses and/or replication studies to avoid the risk of false-positive findings.

An important step in analysis of genome-wide association studies data that needs to be considered is the conduct of rigorous quality control procedures before conducting the final association analyses. Relevant guidelines include [Guideline for data analysis of genomewide association studies](#) (Cancer Genomics Proteomics 2007; 4(1): 27-34) and [Statistical Optimization of Pharmacogenomics Association Studies: Key Considerations from Study Design to Analysis](#) (Curr Pharmacogenomics Person Med 2011; 9(1): 41-66).

10.3.6. Reporting

The guideline [STrengthening the REporting of Genetic Association studies \(STREGA\)--an extension of the STROBE statement](#) (Eur J Clin Invest 2009; 39(4): 247-66) should be followed for reporting findings of genetic studies.

10.3.7. Clinical practice guidelines

An important step towards the implementation of the use of genotype information to guide pharmacotherapy is the development of clinical practice guidelines. Several initiatives have been developed to provide these guidelines such as the [Clinical Pharmacogenetics Implementation Consortium](#). Furthermore, several clinical practice recommendations have been published, for example [Recommendations for HLA-B*15:02 and HLA-A*31:01 genetic testing to reduce the risk of carbamazepine-induced hypersensitivity reactions](#) (Epilepsia 2014; 55(4): 496-506) or [Clinical practice guideline: CYP2D6 genotyping for safe and efficacious codeine therapy](#) (J Popul Ther Clin Pharmacol 2013; 20(3): e369-96).

10.3.8. Resources

An important pharmacogenomics knowledge resource is available through [PharmGKB](#) that encompasses clinical information including dosing guidelines and drug labels, potentially clinically actionable gene-drug associations and genotype-phenotype relationships. PharmGKB collects curates and disseminates knowledge about the impact of human genetic variation on drug responses.

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