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Are novel, non-randomised analytic methods fit for decision-making? The need for prospective, controlled and transparent validation

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Abstract

Real World Data (RWD) and patient-level data from completed randomised controlled trials (RCTs) are becoming available for secondary analysis on an unprecedented scale. A range of novel methodologies and study designs have been proposed for their analysis or combination. However, to make novel analytical methods acceptable for regulators and other decision makers will require their testing and validation in broadly the same way one would evaluate a new drug: prospectively, well-controlled and according to pre-agreed plan. From a European regulators' perspective, the established methods qualification advice procedure with active participation of patient groups and other decision makers is an efficient and transparent platform for the development and validation of novel study designs.

Introduction

The opportunities for learning fast about drugs' benefits and harms have never been greater. The past decade has seen impressive changes in the generation and availability of health related data. The majority of patient-provider interactions in developed healthcare environments are now recorded electronically and electronic health records (eHRs) have been made available for secondary use to answer research questions. On another frontier, patient-level data from completed randomised controlled trials (RCTs) are now being shared on an unprecedented and growing scale. This enables cross-trial analyses and, though more challenging, combining RCT data with different types of "real world data" (RWD), including eHRs and insurance claims. Lastly, new data sources, including the medical internet of things, wearables, social platforms or smart phone apps might possibly be mined in future for healthcare relevant information.

A number of obstacles will have to be overcome before the full potential of these data sources can be brought to bear on pharmaceutical research and care. The obstacles have been broadly grouped in two domains¹: (i) technical/operational readiness, which relates to factors like extent of eHR coverage, use of structured data, interoperability of databases, and data quality; and (ii) data governance readiness, which addresses legal issues impeding secondary data analysis, including data privacy concerns, level of consent required, and clarity on who has legal access to health data for research purposes. A recent OECD report highlighted that all OECD countries still face challenges in both domains¹. Applicability of RWD across healthcare systems remains an additional issue.

Yet, we are optimistic. As the ecosystem for e-health develops, so will data quantity. Issues of data quality, including missing data, and differences in terminologies and data formats will be

more challenging to resolve². However, the need for quality assurance and control procedures has been recognised and a range of initiatives are aiming to bring RWD quality to a level of regulatory acceptability. Collaborations amongst stakeholders and opportunities for data processing and quality improvement are constantly growing^{3, 4}. Progress will likely happen in fits and starts but we foresee a future where healthcare data from different sources and of sufficient quantity and, eventually, quality will be available for rapid secondary analysis by researchers. Some secondary use of RWD is well established⁵, e.g. drug utilisation, disease epidemiology, or safety evaluation⁶. However, if fully exploited, RWD could also contribute to e.g. demonstrating efficacy and treatment stratification to inform regulatory, reimbursement and personalised treatment⁷ decisions. The broad range of research questions that might be addressed with the help of new data sources have been described elsewhere^{4, 8}.

Methodology aversion

Alas, *data*, even of good quality, do not necessarily translate into credible *evidence* in the absence of adequate (statistical) methods to extract, analyse, and interpret them^{2, 9}. Addressing this obvious bottleneck, a range of relatively novel methodologies have been proposed or refined over the past decade to enable the analysis of RWD or to combine RWD with RCT data.

Unsurprisingly, proponents of these methodologies argue that they can address potential biases and deliver robust evidence. However, many commentators remain unpersuaded and argue that acceptance of non-RCT methodologies is tantamount to lowering the quality of evidence because these methods are prone to a myriad of undetected or undetectable biases. The pros and cons of non-RCT methodologies have been aired extensively and will not be repeated here.

The RCT will, in our view, remain the best available standard and be required in many circumstances, but will need to be complemented by other methodologies to address research questions where a traditional RCT may be unfeasible or unethical.

It is self-evident that uncritical adoption of novel methodologies may lead to false conclusions, poor healthcare decisions and, ultimately, patient harm. However, the opposite - that is, *not* to use novel, robust methodologies - has equally detrimental consequences: Bauer and Koenig¹⁰ coined the term “methodology aversion in drug regulation” referring to a purported unwillingness of regulators (and presumably other decision makers) to adopt novel statistical or other methods of data analysis. Some part of the unwillingness may stem from a fear that, “without in-depth knowledge, [...] toolboxes may quickly turn into black boxes”. In turn, this fear may be

precipitated by a lack of familiarity with new methodologies, partly due to conservatism, partly to lack of resources¹⁰.

We concur that unfounded methodology aversion is a potential roadblock to making the best use of new data sources. Regulators have been accused of methodology aversion (though they are often simultaneously accused of recklessly abandoning the “gold standard” RCT) but we see various degrees of methodology aversion in all stakeholder groups within the pharmaceutical ecosystem.

Methodology development by design

How can we overcome methodology aversion without the risk of adopting unreliable study designs? We believe the appropriate course of action is to take a break from the often heated exchanges and start to evaluate and validate novel statistical, epidemiological or other methodologies² in broadly the same way one would evaluate a new drug: prospectively, well controlled and according to pre-agreed plan.

Table 1 lists a number of non-RCT methodologies that have been proposed in the context of the assessment of drugs. The list is neither exhaustive nor definitive but has been compiled on the basis of commonalities that these methodologies share:

- their concept and theoretical underpinnings have been developed in detail;
- the potential gains from their use for drug development and assessment could be considerable in terms of resource and time savings and in getting more relevant information on the effectiveness and safety of medicines to patients faster;
- lack of confidence in these non-(or not fully) randomised designs is limiting their impact;
- sharing of patient-level RCT data and RWD will be key enablers of these methodologies;
- we are not starting from scratch: at least some validation efforts have already been made, if only by individual parties, e.g. individual companies or academic groups, or the method is already in use but has not been thoroughly tested and accepted;
- it is perfectly feasible to validate these methods in a prospective controlled way, often by “bolting-on” the methods validation exercise to a standard drug development plan or RCT;
- prospective evaluation will not require additional de novo data generation, hence can be relatively low cost.

[Table 1 here]

We emphasise the last two bullet points: there are no unsurmountable obstacles to designing a prospective evaluation plan for any of these methodologies in the context of and in parallel to routine pre- and post-marketing drug development programs. Compared to the cost and timelines of *de novo* data generation in an interventional trial, the resource requirements appear not prohibitive.

How could these methodologies be prospectively tested and validated in practice? Consider, for example, the first two topics in Table 1. Prospective evaluation of these methodologies can be built into the planning of conventional two-arm RCTs. Provided there are relevant RWD or patient-level data from previous RCTs available that conform to the RCT selection criteria and to the control treatment (placebo, no treatment, a defined standard treatment or best supportive care), an add-on analysis can be planned to compare the level of agreement between the standard intergroup comparison of the randomised groups with the comparison between the experimental group from the RCT and the control group with borrowed data (or the virtual external control group). The prospective analysis plan needs to ensure that the conduct and interpretation of the RCT itself is not compromised but at the same time needs to ensure credibility of the methods-evaluation exercise; i.e. the exercise should be free from post-hoc bias; it must not “paint the bull’s eye around the arrow”.

Arguably the most controversial among the methods listed in Table 1 is the concept of replacing RCTs by RWD analysis. It is tempting to compare the effectiveness of two drug treatments that have been on the market for some time by way of retrospective RWD analysis. The strengths and limitations and the types of research questions that could potentially be addressed by RWD instead of an RCT have been reviewed elsewhere¹¹. Compared to running a head-to-head RCT, RWD analysis could obviously lead to cost and time savings. However, the track record of non-randomised comparative studies is not convincing. In some high-profile cases, findings from subsequent RCTs differed not only in effect size but even in direction, resulting in qualitatively different causal conclusions¹².

Can we improve the track record? Proponents of RWD analysis would argue that we have learned from past mistakes and the field has strengthened in the past decades. Indeed, there are some encouraging examples where RWD studies correctly predicted RCT results *before* the RCT results became available¹² (but we do not know how many unpublished RWD studies did not correctly predict RCT results). The prospective nature of the exercise needs re-emphasising, since analysing RWD after the RCT is always fraught with the risk that the design and analysis will be tuned to the known RCT findings. Only the prospective, structured evaluation of RWD studies to match the results of RCT in different clinical settings can avoid potential for post-hoc

adjustments. Projects are currently underway to that intent¹³. The FDA has developed and is now funding targeted demonstration projects¹⁴. We are aware that interest in conducting head-to-head RCTs in the post-marketing phase is often limited, but what is needed is at least several RCTs comparing two (or more) treatments that have been on the market for a sufficient period of time to enable simultaneous RWD analysis. This would provide an opportunity to “bolt-on” a methods evaluation exercise by simultaneously developing the RCT protocol and the parameters of the RWD analysis which is to be conducted concurrently with the RCT but before RCT results become available.

Along similar lines, the conduct of a post-marketing head-to-head RCT¹⁵ can be used to prospectively plan for the comparison of different methods for indirect or mixed treatment comparisons, provided that previous common-comparator RCTs (e.g. against placebo) are available for the drugs to be compared. The exercise could help explain discrepancies in results from different methods, and to cross-validate methods against each other. As above, the benefit of running the exercise during the planning stages of the head-to-head RCT is to avoid that design and analysis choices are tuned to match the known RCT results.

For some methodologies listed in Table 1, the validation exercise will have to be done during the post-marketing phase. For example, predictions of efficacy, optimal dosage, or safety based on extrapolation from a source population (e.g. adolescents) to a target population (e.g. younger children or infants) made at the time of marketing authorisation can only be assessed at a much later stage, i.e. once sufficient clinical experience in the target population has accumulated. Yet, the validation plan should be formulated proactively and agreed upon at the time when the extrapolation is performed.

The overall goal of the parallel validation exercises described above and in Table 1 is to gain practical experience with novel analytical methodologies. The technical goals are to:

- see where they can or cannot be used;
- understand why some studies fail while others succeed;
- avoid design or analytic flaws that have plagued much of non-randomised research;
- allow for sensitivity analyses to explore whether alternative designs could increase the level of agreement between the novel and conventional methodologies;
- define if any characteristics can predict with high certainty the validity of a non-conventional study or analysis.

As experience grows, the scientific field will mature, decision-makers will have robustness-checks in place and confidence in the reliability of results will grow - if justified.

How much work needs to be done before a given new analytic method can be declared fit-for-decision-making? We would caution against the expectation of a simple answer. The potential impact of relying on inappropriate methodology is context dependent. The impact is comparatively small when new methods are merely used to support additional evidence, since regulatory and other decision makers are used to looking at the totality of evidence, based on information coming from different types of data and methods. Examples include scenarios where positive benefit-risk has been established by conventional means on the basis of pivotal RCTs and their pre-defined primary endpoint(s) and novel methodologies are merely used for analysis of a secondary endpoint, or for extension of the label to a (biologically similar) indication of a late-comer in a given therapeutic class. It would seem prudent for decision-makers to first accept novel analytic methods for such lower risk situations and then gradually expand acceptability as confidence in the method grows.

Returning, for example, to the controversial question of whether RWD can ever replace RCTs (Table 1 and above), we believe the answer at this point in time should be neither a categorical no or yes but an open-minded, prospective exploration to identify scenarios where RWD analysis can provide sufficiently robust, decision-relevant supportive evidence.

Most of the methods listed in Table 1 rely (partly) on the use of RWD. Healthcare systems and healthcare environments are different from one country to another and it is often argued that RWD cannot easily be extrapolated across regions. We concur but emphasise the difference between data sources and analytic methods, where there are bigger opportunities for improvement. While the results of a given RWD analysis from, e.g., the US may not be relevant for a healthcare environment in the EU (or vice versa), the learnings from methods development on how to, say, address a given type of bias, are expected to have global relevance.

The European Medicines Agency (EMA)'s regulatory science strategy and methods qualification procedure

Recognising the fast pace of innovation and its own role in catalysing and enabling regulatory science and innovation, EMA has recently published its newly developed regulatory science strategy¹⁶ (RSS).

One of the key goals identified in the RSS is “Driving collaborative evidence generation - improving the scientific quality of evaluations”; the public health aims of this drive are to “provide regulators and [Health Technology Assessment bodies] HTAs/payers with better evidence to underpin regulatory assessment and decision-making” and “advancing patient centred access to

medicines". The strategy lists a number of core recommendations and proposed underlying actions. These include fostering innovation in clinical trials (with a focus on novel trial designs, statistical concepts, endpoints, or techniques for gathering data) and developing methodology to incorporate clinical care data sources in regulatory decision-making. The study designs and methodologies listed in Table 1 are representative (but not exhaustive) of the novel methodologies that could be explored in the context of the RSS.

EMA has been offering for some time a scientific advice procedure "to support the qualification of innovative development methods for a specific intended use in the context of research and development into pharmaceuticals."¹⁷ The process foresees an initial consultation and advice phase with repeated interactions between innovators and regulators to define what studies or other activities will be required to qualify a new methodology "fit for purpose". At that stage, for methodologies which appear promising, EMA publishes a letter of support after agreement with the sponsor¹⁷. The advice phase is followed by a formal opinion on the acceptability of the specific use of a method. Before final adoption of a qualification opinion, after agreement with the sponsor, the evaluations are made available for public consultation by the scientific community; for specific examples, please refer to ¹⁸ and ¹⁹. This is to ensure that all relevant information is open to scientific scrutiny and discussion.

Several methodology advice procedures have been successfully concluded or have started in collaboration with EU HTA bodies and patient groups. The hoped-for result of such collaborative efforts is the widest possible acceptance of useful methodologies by key healthcare decision-makers, beyond regulators only.

We believe that the qualification advice procedure with active participation of HTA bodies, healthcare payers and patient groups is an efficient, transparent and inclusive platform for the development and validation of novel study designs such as those summarised in Table 1. We invite researchers from academia, industry and public-private consortia to avail themselves of this opportunity to open up their methodology developments to external scrutiny and, in the process, familiarise decision makers with their concepts – which is the best way to enhance their acceptability, if justified.

Conclusion

Our goal has been to draw attention to a potential roadblock in the use of new data sources: methodology development, and its flip side, methodology aversion. It will not be sufficient for researchers to elaborate novel study designs and analyses. A necessary and self-evident second

step is the testing and validation of any such approaches with a view to avoiding the “black-box trap”, that is to jeopardise the acceptance of even a useful method because it cannot be understood by external stakeholders who were not involved at any stages of the development⁵.

To overcome methodology aversion, also the developers of new methods should prospectively address “data aversion” and new methods should be tested both retrospectively utilizing the open-access to RCT and RWT data and prospectively as discussed.

Transparent, collaborative platforms such as EMA’s methods qualification procedure or similar procedures offered by the US FDA and other public bodies are likely the best available avenues to achieve goal.

The ultimate key to achieving credibility is to start with an open but “agnostic” mind-set and submit novel methods to a fair, transparent and *prospective* validation exercise; this cannot be done only by dry runs with old products. It is understandable that drug developers are wary of jeopardising the development programs for their valued new assets. However, we emphasise that if developers want trial assessors to accept novel methods, they will have to expose some of their experimental drugs to methodology development exercises. This would need to happen with a clear upfront agreement on a “firewall” between the methods-evaluation and the product-evaluation, with assurances that the methods evaluation will neither jeopardise nor rescue a product. We are confident that, with proper planning, optimal drug development can be combined with optimal methodology development.

We are also aware that methodology developments are labour-intensive activities that will require the collaboration of methodologists, drug developers, patient representatives, data custodians, and prospective trial assessors (regulators, HTA bodies, payers), as well as adequate funding streams. We hope that funding bodies such as the EU Innovative Medicines Initiative²⁰ will support development of methodologies that require public-private partnerships and represent a paradigm shift that would benefit a range of therapeutic areas or products. Funds will need to be dedicating over the prolonged periods of time needed to see methods development through all stages from exploration to validation and acceptance. To revisit the analogy with drug development, these are long-term projects that will not come to fruition as a result of short term efforts by individual players.

The stakes are high - overcoming methodology aversion and ensuring that all stakeholders arrive at a nuanced view between categorical rejection and naïve adoption of novel methods.

Table 1. Examples of (novel) methodologies, in no particular order, for analysis of different types of data that would benefit from prospectively designed validation.

Methodology	Potential benefit for drug developers and decision-makers	Current limitations	How to validate prospectively
Borrowing of data ^{21 22 23}	“Borrowing” cases from past studies for the control arm of a current RCT could increase the efficiency of decision making with the current study. This may translate into smaller sample size for the current trial and/or unequal randomisation.	Relies on the assumption of similarity of historical information to the current control data; may result in bias if assumption is not satisfied. Several methods for historical borrowing have been proposed.	Use conventional RCTs to concurrently analyse results as per usual and with borrowed data according to pre-planned protocol and data sources. Compare and assess various methods of borrowing.
Use of external control group, threshold crossing ^{24 25}	May enable causal inferences about drug effects on the basis of external (historical) control groups for products and indications where RCTs are not feasible.	Comparisons with external controls are based on assumptions that often cannot be verified which may lead to biased conclusions about drug effects ²⁶ . External control groups tend to have worse outcomes than a similar control group in an RCT ^{27 28} .	Use conventional RCTs to concurrently analyse results as single-arm trials with historical comparators; compare results from the randomised and non-randomised analyses based on pre-agreed plan ²⁵ .
Indirect comparisons for relative efficacy ^{29 30}	Allows for estimation of relative efficacy of two (or more) treatments in the absence of any head-to-head RCTs (=direct comparisons) Frequently used by HTA bodies for REA, since many (new) drugs have	While indirect comparisons usually rely on randomised data, the treatments of interest have not been randomised against each other (head-to-head), only to a common comparator. A variety of methods exist	Use the opportunity afforded by the planning of a head-to-head RCT where previous RCTs of the drugs of interest against a common comparator (e.g. placebo) are available to develop a prospective analysis plan for indirect

Methodology	Potential benefit for drug developers and decision-makers	Current limitations	How to validate prospectively
	insufficient RCT information for direct comparisons.	to mitigate this, but each method rests on a number of assumptions about the data used. Methods are still evolving and sometimes generate discrepant results.	and MTC. The aim is to compare different methods for indirect or MTC, explain discrepancies in results from different methods, and to cross-validate methods against each other and against the head-to-head RCT.
Replacing RCT by RWD analysis ¹²	Conceptually, RCTs could in some situations be replaced by comparative analyses of RWD. Replacing even a small proportion of post-marketing RCTs with nonrandomized RWD analyses would in many cases translate into faster availability of relevant information using substantially fewer resources.	Major concerns about comparative RWD analyses include lack of ability to tightly control measurements of patient characteristics and health outcomes and susceptibility to bias. A general lack of confidence in nonrandomized RWD analyses has limited their impact.	Prospectively design new RWD studies to match the design of planned RCTs. This is feasible when both drugs have been in routine use for a sufficient time. The concurrent approach avoids bias by matching the RCTs and RWD analyses as closely as possible (e.g. for patient characteristics, dose regimens), while avoiding the temptation to trim RWD analysis to the RCT results once they become available. It also allows for sensitivity analyses to identify whether alternative designs or analyses could have improved agreement between the designs.
Reweighting of RCT results to	Using real-world data, e.g. from disease registries, to	A demonstration project has shown the feasibility	Use results of conventional RCTs of novel drugs to

Methodology	Potential benefit for drug developers and decision-makers	Current limitations	How to validate prospectively
reflect real life ³¹ ³²	“reweight” RCT results may improve external validity and generalizability of RCT results.	but the concept has not been prospectively validated.	obtain reweighted results and compare to measured outcomes once enough RWD has accumulated; according to pre-planned protocol and data sources.
Extrapolation of knowledge to an unstudied population ^{33 34}	<p>In some populations (e.g. neonates or young children), the conduct of clinical trials is fraught with operational or ethical challenges leading to an absence of information on drug effects. “Implicit extrapolation”, though subjective, is often the only basis for treatment or dosing decisions in these populations.</p> <p>A systematic framework for “explicit extrapolation” of relevant information from a source population (e.g. adults), to a target population (e.g. small children) preferably based on quantitative methodology has the potential to improve treatment decisions.</p>	Whilst some of the methods proposed for the extrapolation exercise are not novel, experience with their use in extrapolation exercises is limited. Few, if any, systematic extrapolation exercises have undergone prospective validation.	<p>As clinical experience grows during the post-marketing phase, the assumptions and predictions made on the basis of extrapolations can be checked against prospectively planned collection of RWD.</p> <p>Apply the concept of extrapolation also in areas where RCTs are possible, e.g., extension of indications in adults where further RCTs are conducted and compare whether the extrapolation concept (requiring different/less data) would have resulted in similar results. Assess various concepts of extrapolation simultaneously. Might require that some additional data are collect in the current RCT (such as PK/PD)</p>

Methodology	Potential benefit for drug developers and decision-makers	Current limitations	How to validate prospectively
<p>Predictive approaches to heterogeneous treatment effects^{35 36 37}</p>	<p>(Positive) RCTs can only help predict that at least some patients similar to those enrolled in the trial will likely benefit from the intervention (“reference class forecasting”). However, determining the best treatment for an individual patient is different from determining the best average treatment, because of heterogeneity of treatment effects.</p> <p>Improved prediction of outcome risk and understanding of heterogeneity of treatment effect could be key enablers of personalised treatment decisions and more successful treatment outcomes.</p>	<p>Conventional subgroup analyses, aiming to describe effect modifiers, often fall short because each patient belongs to multiple different subgroups, each of which may yield different inferences.</p> <p>More elaborate, regression-based approaches have been proposed to address heterogeneity of treatment effect, including risk modelling and treatment effect modelling.</p> <p>However, experience with these methods is limited, especially with externally derived models. There have been few, if any, attempts to systematically evaluate their usefulness in clinical practice.</p>	<p>Develop models concurrently with the design of an RCT. Where possible, incorporate assessment of the use of RWD for predictive analysis of heterogeneity of treatment effect.</p> <p>The ultimate test of a predictive approach is to compare decisions or outcomes in settings that use such predictions with usual care in a prospectively planned experiment³⁵.</p>

Abbreviations: HTA = health technology assessment; MTC = mixed treatment comparison; PK/PD = pharmacokinetics/pharmacodynamics; RCT = randomised controlled trial; REA = relative effectiveness assessment; RWD = real world data

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