Personalising biologic therapy in psoriasis: Development, validation and user-testing of a precision dosing dashboard

Short: Precision dosing of biologics in psoriasis

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ABBREVIATIONS

TDM; therapeutic drug monitoring, MIPD; model-informed precision dosing, PK; pharmacokinetic, PD; pharmacodynamic, IMID; immune-mediated inflammatory diseases, MAE; mean absolute error, MPE; mean percentage error, RMSE; root mean square error, CL; clearance, F; bioavailability

KEYWORDS

model-informed precision dosing, data-driven dosing, immune-mediated inflammatory diseases, therapeutic drug monitoring

ABSTRACT

Rising numbers of individuals receiving psoriasis biologics achieve clear/nearly clear skin (disease control). Trial data indicate some maintain control with lower doses, especially those with higher serum drug concentrations. This indicates potential for Model-Informed Precision Dosing (MIPD), an advanced therapeutic drug monitoring technique, in guiding dose minimisation. We developed, validated, and user-tested a precision dosing dashboard. We applied a MIPD approach leveraging Bayesian estimation to predict

individual pharmacokinetic (PK) parameters for personalised dosing recommendations. A PK model of the exemplar biologic risankizumab, derived from phase I-III psoriasis trial data (13123 observations/1899 patients), was externally validated using real-world UK psoriasis data. The Bayesian model (posterior prediction: mean absolute error 0.89 mg/L; mean percentage error 19.55%; root mean square error 1.24 mg/L; R^2 0.86) had superior predictive power to the basic PK model (prior prediction). The model was incorporated into an interactive dashboard, enabling input of individual patient data (serum drug concentrations, model covariates). UK healthcare professionals rated the dashboard user-friendly and acceptable. Mean time to generate a dosing interval was 2 minutes. Our dashboard has potential to incorporate other biologics and extend across disease contexts (non-response, other inflammatory diseases) for optimal real-world impact of precision dosing on health and cost outcomes.

1 INTRODUCTION

Psoriasis is a chronic immune-mediated inflammatory disease (IMID) that has a prevalence of 1-3.5% in Western Europe (Parisi et al. 2020) and requires lifelong management. The introduction of targeted biologic therapies has changed the landscape of psoriasis treatment, with up to 86% of individuals achieving clear or nearly clear skin (disease control) after 16 weeks of therapy (Blauvelt et al. 2017a); (Warren et al. 2021); (Reich et al. 2019); (Thac¸i et al. 2015); (Reich et al. 2021). Once disease control is achieved, patients often remain on therapy indefinitely. This entails regular injections and clinic appointments and raises concerns about the uncertain long-term implications of immune modulation, risk of dose-dependent infections and rare serious adverse events (Singh et al. 2015); (Kalb et al. 2015); (Yiu et al. 2019); (Mahil et al. 2013). Biologic drugs are also costly, and so are currently reserved for those with the most severe disease (National Institute for Health and Care Excellence 2019). The substantial burden on patients and healthcare systems, coupled with limited access, underscores the need for reform in therapy approaches.

Previous studies suggest that higher serum drug concentrations are associated with

better biologic treatment outcomes (Menting et al. 2015); (Soenen et al. 2024); (Mostafa et al. 2017); (Khatri et al. 2020). However, after a concentration threshold has been met, the clinical response begins to plateau (Khatri et al. 2020). There is evidence to show that some patients may sustain disease control with lower doses than the current one-size-fits-all standard regimens, highlighting an opportunity for drug concentration-guided dose minimisation (Blauvelt et al. 2017b); (Carrascosa et al. 2015); (Baniandres et al. 2015); (Esposito et al. 2017); (Riel et al. 2024); (Herranz-Pinto ´ et al. 2023); (Atalay et al. 2020); (Bezooijen et al. 2017); (Dauden et al. 2024); (Bardazzi et al. ´ 2016); (Fotiadou et al. 2012); (Hansel et al. 2017); (Ovejero-Benito et al. 2020); (Piaserico et al. 2016); (Reich et al. 2020); (Romero-Jimenez et al. 2016); (Eyerich et al. 2024); (Aubert et al. 2023); (Michielsens et al. 2021).

Therapeutic drug monitoring (TDM) involves adjusting drug dosing based on serum concentrations in order to maintain a target concentration. Conventional TDM practices are based on non-precise serum drug concentration intervals, do not take into account the variability across patients, and are often restricted to set time points in the treatment cycle which can be difficult to implement in practice. In contrast, model-informed precision dosing (MIPD) is an advanced discipline within TDM that employs quantitative techniques to enable individualised dosing using mathematical and statistical models (Perez-Blanco et al. 2022). Model-informed precision dosing is a precise, personalised and flexible TDM approach that considers heterogeneity within the population. The rise in published population pharmacokinetic (PK) models for biologics over recent years has enabled model-informed precision dosing developments. However, translation into clinical care remains a challenge due to the lack of practical guidance for implementation.

The need for a framework to execute precision dosing is evidenced by an international survey of dermatologists (n=53), which highlighted that a key barrier to dose optimisation is the lack of guidance. The study found that 70% of dermatologists are already performing dose reduction in some capacity, with 86% citing cost savings as the primary reason (Muijen et al. 2022). This finding aligns with a separate international (predominantly European) structured survey of dermatologists (n=107), which revealed that 71% have

altered biologic dosing for psoriasis in their practice. 95% of dermatologists were at least familiar with TDM and around 70% recognised the need for TDM of biologics in clinical practice (Schots et al. 2022). Despite biologic dose changes taking place in real-world care and clinician acceptability of TDM, dose alterations are largely empirical rather than data-driven, underscoring the need for guidance.

Dashboards can be used to package complex mathematical models into accessible applications. We present a user-friendly dashboard for the implementation of model-informed precision dosing and offer a pipeline for delivering novel data-driven precision dosing of biologics in psoriasis care. In this proof of principle study, we have selected the highly effective IL-23 p19 subunit inhibitor risankizumab (Skyrizi®). Clinical trial data indicate that 53–73% of patients receiving risankizumab attain clear or nearly clear skin at week 16 (Reich et al. 2019); (Gargiulo et al. 2024); (Mastorino et al. 2022); (Blauvelt et al. 2020). A phase III randomised controlled trial showed that 61.3% (138/225) of patients maintained clear or nearly clear skin 24 weeks after discontinuing 28-week risankizumab treatment (Blauvelt et al. 2020), highlighting the potential for dose minimisation in well-controlled psoriasis. We therefore sought to develop, validate and user-test a precision dosing dashboard for risankizumab using Bayesian estimation to generate personalised biologic dose recommendations for sustaining disease control.

2 RESULTS

2.1 Selection of pharmacokinetic model

Of 11 articles identified in the literature search (8 from PKPDAI and 3 from PubMed), 3 were review articles, 4 pertained to an inappropriate patient population (e.g. psoriatic arthritis, exclusively Asian population) and 3 did not use a compartmental approach for model development. We identified 1 suitable population PK model for risankizumab (Suleiman et al. 2019). The published population PK model was well described in the relevant disease indication (psoriasis). It was a two-compartment PK model with first-order absorption and elimination processes derived from pooled phase I to III risankizumab

clinical trial data. The study population consisted of 13123 observations from 1899 patients with moderate to severe plaque psoriasis (71% male; median age 47 years; median body weight 87 kg; median BMI 29.4) who were receiving standard dosing of risankizumab. Reported model covariates were weight and serum concentrations of albumin, creatinine, CRP and anti-drug antibody. The PK model was successfully translated into R using rxode2.

2.2 Performance validation

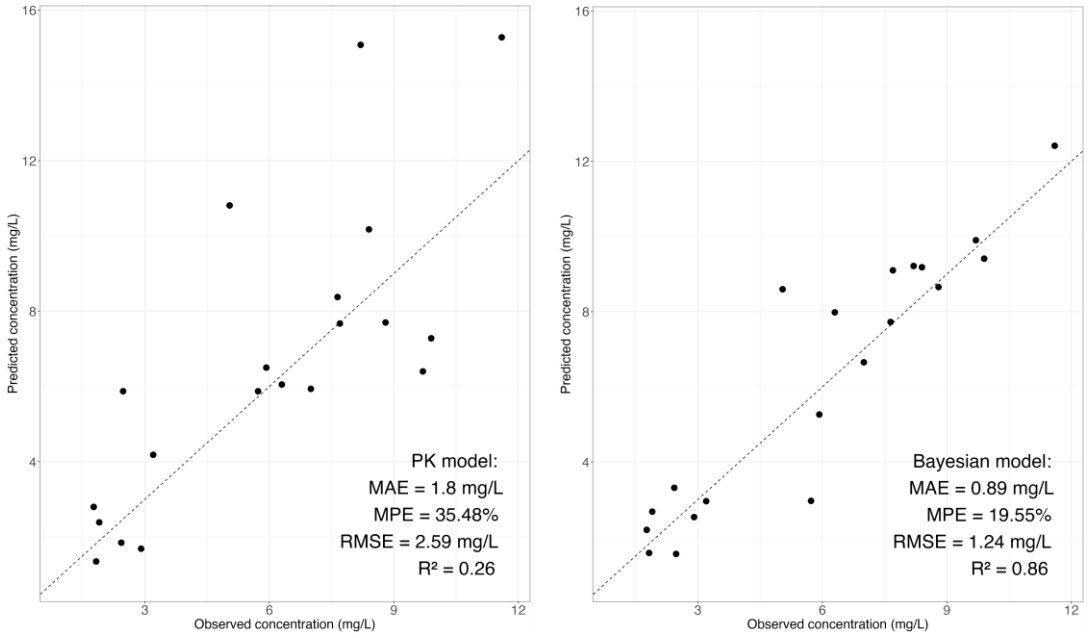
Our independent real-world validation dataset consisted of 75 individuals. 20 participants were suitable for validation since they had at least 2 serum risankizumab measurements at different time points during treatment (Table 1). All validation participants had serum anti-risankizumab antibody concentrations below the level of quantification (< 10 ng/mL) and CRP concentrations either unavailable or below the limit of quantification (< 1 mg/L).

Validation of the model demonstrated that Bayesian estimation (personalised/ posterior) was superior to the basic PK model (initial/prior). The mean absolute error (MAE) was 0.89 mg/L for the Bayesian estimation compared to 1.8 mg/L for the basic PK model. The mean percentage error (MPE) for the Bayesian estimation was 19.55% versus 35.48% for the basic PK model. The root mean square error (RMSE) for the Bayesian estimation was 1.24 mg/L compared to 2.59 mg/L for the basic PK model. Finally, the coefficient of determination (R^2) was 0.86 for the Bayesian estimation versus 0.26 for the basic PK model, indicating a stronger correlation between predicted and observed values (Figure 1).

Table 1: Baseline characteristics of the validation cohort

Characteristic	Median (range) or n (%)
Sex (male)	11 (55%)
Ethnicity (white)	17 (85%)
Age (years)	50 (18, 75)
Weight (kg)	85.8 (53, 119)
BMI (kg/m²)	27.9 (20.4, 39.3)
Baseline PASI	3.3 (0, 40.8)
Albumin (g/L)	43 (37, 50)
Creatinine (µmol/L)	74 (51, 120)
Creatinine clearance (mL/min)	1.3 (0.8, 1.9)
Time on treatment (weeks)*	46.6 (2, 180.1)

Characteristics are presented as median (minimum, maximum) or n (percentage). Total n=20. PASI is Psoriasis Area and Severity Index. * at prediction serum drug concentration.



(a) PK model - prior (b) Bayesian model - posterior

Figure 1: Model predicted vs observed serum risankizumab concentrations for basic PK model (a) and Bayesian model (b). The line of identity is displayed. MAE is mean absolute error, MPE is mean percentage error, RMSE is root mean square error and R^2 is the coefficient of determination.

2.3 Integration into the precision dosing dashboard

From the literature, we selected average serum drug concentration as our drug target to inform drug dosing intervals (our intervention) to derive precision dosing recommendations. Phase II-III trial data indicated that 85% of psoriasis patients achieved 90% improvement in PASI from baseline (PASI90) at week 52 at an average serum risankizumab concentration of 5.4 mg/L, after which response plateaued (Khatri et al. 2020). An average serum risankizumab concentration of 5.4 mg/L was therefore selected as our drug target to generate personalised dosing interval recommendations, in patients who have achieved steady state serum risankizumab levels, using the precision dosing dashboard.

Personalised dosing interval recommendations were generated by extracting individual clearance (CL) and bioavailability (F) parameters (generated from the posterior prediction) to calculate the required dosing interval to reach the target average concentration:

$$\text{dosing interval} = \frac{F \times dose}{CL \times C_{target}}$$

where: F is bioavailability, dose is in mg (150mg), CL is clearance in L/day and C_{target} is a target average concentration (5.4 mg/L).

The model and PK equation were successfully integrated into a bespoke R Shiny dashboard (https://shiny-tdm.sites.er.kcl.ac.uk). The online dashboard is a single screen that enables the user (i.e. a healthcare professional) to input all necessary information to generate a personalised dosing recommendation (Figure 2). A Bayesian 'prior' was generated from the population PK model (hidden from the user) and model covariates

(body weight, serum concentrations of albumin, creatinine, CRP and anti-risankizumab antibody). The prior prediction is combined with additional information entered into the dashboard by the user on the patient's dosing history (date of last dose) and serum drug concentration measurements to generate a 'posterior' or 'personalised' prediction of the patient's PK parameters.

The dashboard allows the user to enter up to three serum drug concentration measurements per patient using a drop-down box. Since the population enrolled in our clinical trial (within which the dashboard has been immediately deployed) have received standard biologic dosing for at least one year, a steady state of drug concentration is assumed. All numeric input fields were designated soft and hard limits to mitigate against data entry errors: unexpected but reasonable out-of-range inputs are flagged for user validation using automated error messages, while the entry of extreme out-of-range values is not permitted. If covariate information is not available for an individual, the user can mark it as 'unknown,' and the median value from our validation cohort will be used (Table 1).

Following the selection of the "Calculate interval" button, the dashboard displays the recommended personalised dosing interval and a bespoke dosing schedule based on this interval (Figure 3). The dashboard also displays a graphic comparing the prior (basic PK model) and posterior (personalised) PK profiles (Figure 4). All inputted patient data and the recommended individualised dosing interval are specified in a table within the dashboard, which can be downloaded by selecting the "Download results" button. According to the precision dosing dashboard, prolonged interval dosing was recommended for 65% (13/20) of our validation cohort (median dosing interval 14 weeks, range 12-19).

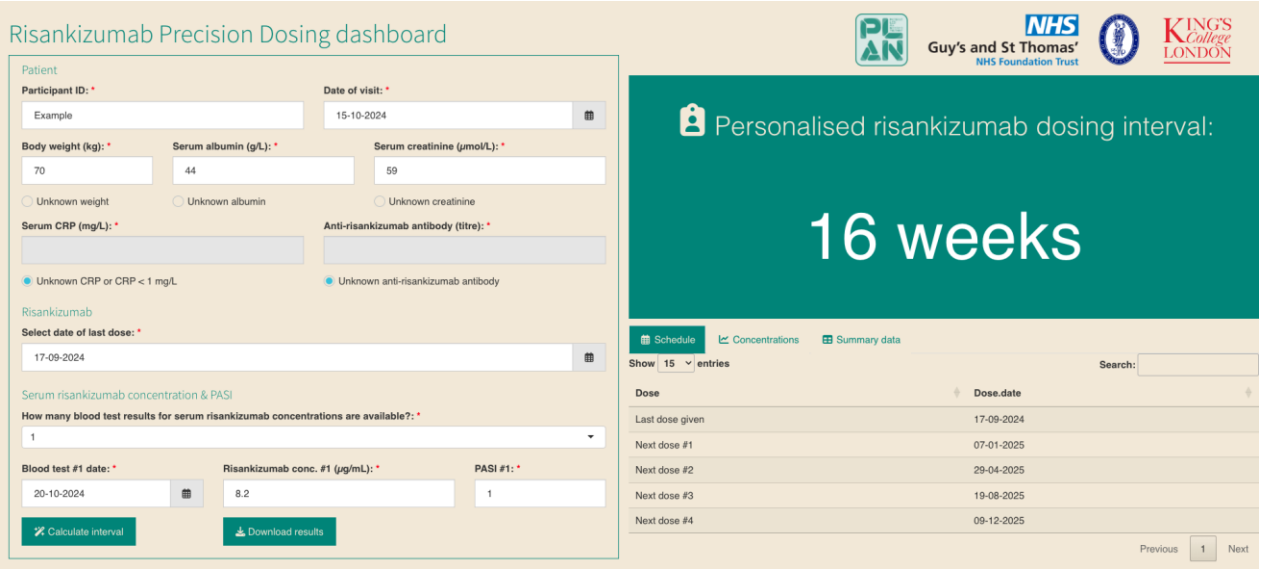


Figure 2: The precision dosing dashboard. Patient covariates, dosing information and serum risankizumab concentrations are inputted by the user. The user selects the "Calculate interval" button, following which the dashboard calculates a personalised dosing interval using the Bayesian estimated PK profile.

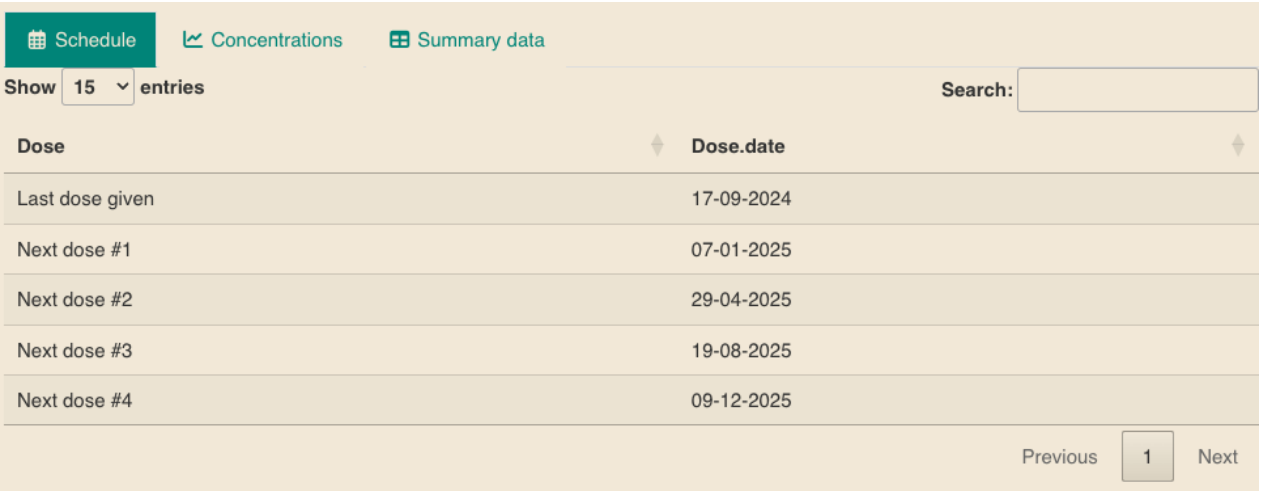


Figure 3: Personalised schedule of biologic doses generated by the precision dosing dashboard. The dashboard provides a bespoke dosing regimen based on the patient's personalised dosing interval, here every 16 weeks.

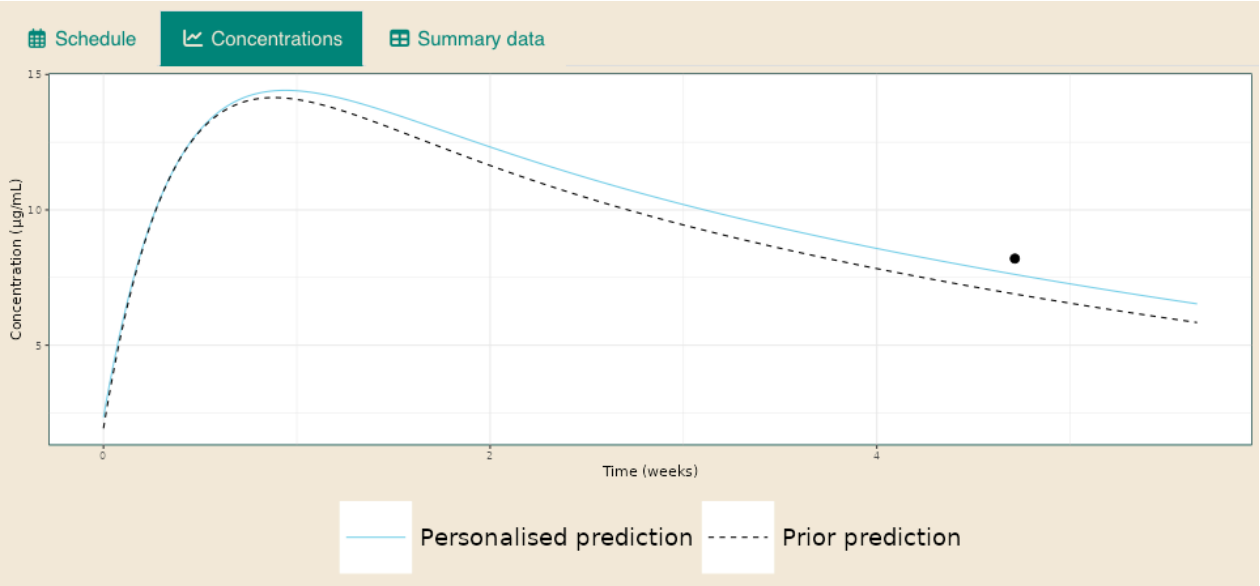


Figure 4: An individual predicted PK profile generated by the precision dosing dashboard. The black dashed line is the prior prediction and the blue line is the patient's posterior (personalised) prediction. The black dot represents the serum risankizumab concentration entered into the dashboard by the user.

2.4 User testing of the precision dosing dashboard

Twenty-nine healthcare professionals from 8 UK dermatology centres assessed the usability of the precision dosing dashboard in 2 user-testing workshops (1st workshop; n=13, 2nd workshop; n=16). The mean age of participants was 41 years, with the majority being female (58%) and of White ethnicity (50%). Most participants were doctors (33%) or nurses (42%) (Table 2).

Following feedback from the first user-testing workshop, several improvements were made to the dashboard layout: the interval output box was enlarged to improve readability, the input boxes were made more prominent by adding a white background, and a warning message was introduced to alert users of missing values. Based on feedback from the second workshop, these warning messages were further refined to highlight which input box(es) had missing data.

The mean time to generate a dosing interval was 1.9 minutes (n=27, SD 1.2). Twenty-four participants completed the feedback survey immediately following the first (n=13/13) and second (n=11/16) user testing workshop. Based on the System Usability Scale,

healthcare professionals rated the usability of the dashboard as “good”, with an above-average score of 74/100. All survey respondents strongly agreed or agreed that “most people would learn to use the precision dosing dashboard very quickly”. 69% (9/13) of healthcare professionals who attended the first user-testing workshop agreed or strongly agreed that the dashboard was “easy to use”, and this increased to 100% (11/11) in the second workshop. Taken together, user feedback and accuracy indicate that minimal training would be required for healthcare professionals to use the precision dosing dashboard independently in clinical settings.

Table 2: Demographic characteristics of participants of the precision dosing dashboard user testing workshops.

	Session 1 (n=13)	Session 2 (n=11)	Total (n=24)
Profession			
Doctor	4 (30.8%)	4 (45.5%)	8 (33.3%)
Nurse	5 (38.5%)	5 (45.5%)	10 (41.7%)
Pharmacist	1 (7.7%)		1 (4.2%)
Trial manager	1 (7.7%)	1 (4.2%)	
Research practitioner		2 (18.1%)	1 (4.2%)
Student	1 (7.7%)		1 (4.2%)
Unknown	1 (7.7%)		1 (4.2%)
Demographic			
Age	40.6 (13.6)	41.9 (8.6)[a]	41.1 (11.6)[b]
Female	9 (69.2%)	5 (45.5%)	14 (58.3%)
White	8 (61.5%)	4 (45.5%)	12 (50%)
Results			
System Usability Scale score	73 (13)	76 (13)	74 (13)
Time to generate interval (min)	1.5 (0.9)[c]	2.4 (1.3)[d]	1.9 (1.2)[e]

Demographics of survey respondents (n=24) from user-testing workshops (n=29 total attendees). [a]n=9; [b]n=22; [c]n=11; [d]n=16, [e]n=27. Results are presented as n (%) except for age, System Usability Scale score and time to generate interval, which are presented as mean (standard deviation). In session 1, two participants calculated the interval and completed the survey, although their generation times were unavailable. In session 2, five participants did not complete the survey but did calculate the interval.

3 DISCUSSION

We successfully created a bespoke precision dosing dashboard for biologic therapy which adopts Model-Informed Precision Dosing (MIPD) using Bayesian estimation. The

dashboard calculates personalised dosing interval recommendations for individuals receiving the exemplar psoriasis biologic therapy risankizumab to maintain psoriasis control. Performance validation, with patients who had baseline characteristics in line with other psoriasis populations (Yiu et al. 2022), demonstrated the superior predictive power of the Bayesian approach (personalised/posterior) compared to the basic PK model (initial/ prior). User-testing of the precision dosing dashboard by 29 multidisciplinary UK healthcare professionals through 2 rounds of evaluations indicated that it is user-friendly and acceptable. We expect the dashboard to be accessible to a wide range of healthcare professionals.

Existing research supports MIPD-guided precision dosing for biologics as a potential strategy to optimise outcomes of biologic therapy. However, substantial implementation barriers exist due to the absence of real-world protocols. Our work addresses this by providing a structured framework for delivering precision dosing in clinical settings using a dashboard. Several dashboards utilising MIPD are commercially available, for example, Insight- Rx, DoseMeRx and PrecisePK (Insight Rx, Inc. 2021 2024); (DoseMe (Tabula Rasa HealthCare Company) 2024); (Healthware Inc 2024) as well as free software, such as NextDose and TDMx (University of Auckland 2024); (Institute of Pharmacy, University of Hamburg 2024); (Kantasiripitak et al. 2020). These dashboards have been leveraged in fields such as infectious diseases, oncology and inflammatory bowel disease, particularly for drugs with narrow therapeutic windows or high PK/PD variability (Minichmayr et al. 2024), but to date there has been limited clinical uptake.

Clinical trials exploring MIPD of infliximab in inflammatory bowel disease (IBD) have shown some promising results (Strik et al. 2021); (Santacana Juncosa et al. 2021), and the recent release of infliximab models by DoseMeRX, PrecisePK, and TDMx highlights the increasing interest in MIPD for IMID biologic therapies. Importantly, a review of dashboards (for MIPD dosing of vancomycin) highlighted that free software options often require significant training and are less user-friendly and that, conversely, user-friendly software such as InSightRx are costly, potentially limiting its adoption in clinical settings (Turner et al. 2018). Our framework addresses several of the challenges presented in the

review, by enabling the creation of precision dosing dashboards that are user-friendly, freely accessible, and offer reproducibility and replicability advantages.

At the time of our literature search, we identified only one population PK model for our drug of interest, which highlights the importance of publishing PK models from clinical trials to provide a foundational resource for the research community. Should more robust PK models become available from future clinical trial data, our dashboard could be easily modified to incorporate new, or multiple (model averaging (Uster et al. 2021)), models. The dashboard is flexible enough to keep pace with developments within the field and can be continuously updated as more information becomes available.

Our framework (Figure 5) is designed to be dynamic. This is particularly relevant in the context of our initial validation cohort, which was limited in size (n=20). The expansion of observational (e.g., BSTOP (REC: 11/HO802/7)) and interventional (e.g., PLAN-psoriasis trial (REC: R24/LO/0089)) datasets can be leveraged for future additional validation, enabling rapid translation into patient and healthcare benefits through the precision dosing dashboard.

Currently, our dosing recommendations focus solely on pharmacokinetics (PK), but incorporating a combined PK-pharmacodynamic (PD) model, using PD outcomes such as the Psoriasis Area and Severity Index (PASI), may offer a more comprehensive approach to personalised dosing (Rodr´ıguez-Fernandez et al. 2024). By considering relevant drug effects (i.e. pharmacodynamics) in addition to serum drug concentration, more heterogeneity in the population can be captured by the model. This approach is already leveraged for drugs such as antibiotics, where the minimum inhibitory concentration is used to inform dosing decisions. Future efforts will involve integrating a PD component into our dashboard to further enhance the precision and effectiveness of our dosing recommendations, as well as comparing performance of the PKPD model with the PK (only) model..

Despite the success of precision dosing in other fields, dashboards are yet to be implemented in clinical care for dermatology. To build on our current work and accelerate implementation in the field, the practicality and acceptability of precision dosing of

biologics, from both patient and clinical perspectives, is being formally evaluated in a feasibility trial (PLAN-psoriasis, REC: R24/LO/0089). The study population comprises patients with clear or nearly clear skin (disease control) for at least 1 year on standard risankizumab therapy. The trial will validate the feasibility of dashboard-led precision dosing, supporting progression towards seeking regulatory approval of the dashboard as a medical device, and explore its benefit in real-world clinical settings.

Our work provides a critical step towards precision dosing of biologic therapy in routine clinical care and highlights a dashboard-based implementation strategy. This personalised medicine approach holds promise for achieving effective, data-driven and patient-centred care, and can be diversified across different biologic therapies and disease contexts for optimal impact on health and cost outcomes.

4 MATERIALS & METHODS

The study workflow for the development, validation and user-testing of the precision dosing dashboard is outlined in Figure 5. The dashboard is currently being implemented in a clinical trial of precision biologic dosing in individuals with well-controlled psoriasis (PLAN-psoriasis feasibility trial, REC: 24/LO/0089).

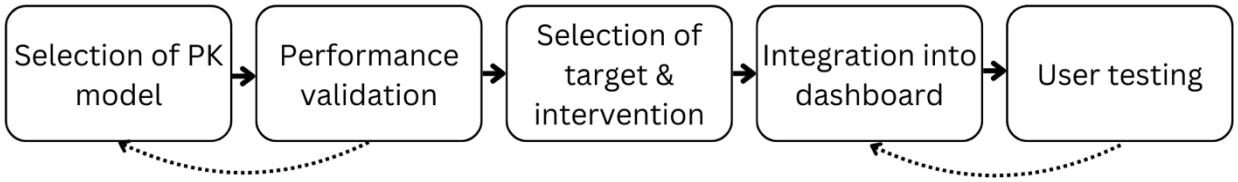


Figure 5: Workflow for the development, validation and user-testing of a precision dosing dashboard. PK; pharmacokinetic. Dotted lines indicate possible iterative adaptations, for example, modifications were made to the dashboard following user testing/feedback.

4.1 Selection of pharmacokinetic model

We searched the PKPDAI publication database (www.pkpdai.com) (Gonzalez Hernandez et al. 2021) and PubMed to identify risankizumab population pharmacokinetic (PK) models. The following search terms were used in PubMed: (risankizumab) AND

(psoriasis) AND ((pharmacokinetics) OR (exposure-response)). Pubmed search results were filtered for studies published after 2021 (after which the PKPDAI database was not up to date). We followed existing guidelines by Taylor et al. (2023) who provide a comprehensive tutorial for selecting a population PK model for dose individualisation. We sought to identify a population PK model that is well-developed and thoroughly described.

4.2 Performance validation

The PK model was first implemented into R (version 4.3.1) (R Core Team 2024) using rxode2 (version 2.1.2.9) (Fidler et al. 2024). Individual Bayesian estimated PK profiles were generated using the MAPBAYR package (version 0.10.0) (Le Louedec et al. 2021). The Bayesian approach generates a 'prior' prediction, which is an initial estimate derived from the published population PK model and patient-specific factors such as body weight. This prior prediction is then refined using the patient's dose history and one or more measured serum risankizumab concentrations to produce a 'posterior' or 'personalised' prediction through Bayesian estimation.

We performed external validation of the Bayesian estimated predictions using a pilot dataset formed as part of the UK real-world multi-centre Biomarkers of Systemic Treatment Outcomes in Psoriasis (BSTOP) study (REC: 11/HO802/7). Serum concentrations included in the validation dataset were above the limit of quantification and from participants who had at least two longitudinal serum risankizumab measurements (one used to generate a posterior PK profile prediction, and at least one to validate the posterior PK profile prediction). For all CRP concentrations below the limit of quantification or unavailable, the lower limit of quantification (1 mg/L) was used. The following model performance metrics were used to compare the basic PK model (prior) with the personalised Bayesian PK model (posterior):

- Mean absolute error (MAE) represents the average absolute difference between predicted and observed values, i.e bias, calculated by:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

• Mean percentage error (MPE) defines the average absolute percentage difference between predicted and observed values, calculated by:

$$\mathrm{MPE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{y_i}\right|$$

• Root mean square error (RMSE) quantifies the average magnitude of the errors between the predicted and observed values, i.e precision, calculated by:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

• R^2 (coefficient of determination) indicates how well the model prediction and observed data align (variance), calculated by:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

where:

- y_i are the observed values,
- $\hat{y}_i$ are the predicted values,
- n is the number of observations,
- $\bar{y}$ is the mean of the observed values.

4.3 Integration into the precision dosing dashboard

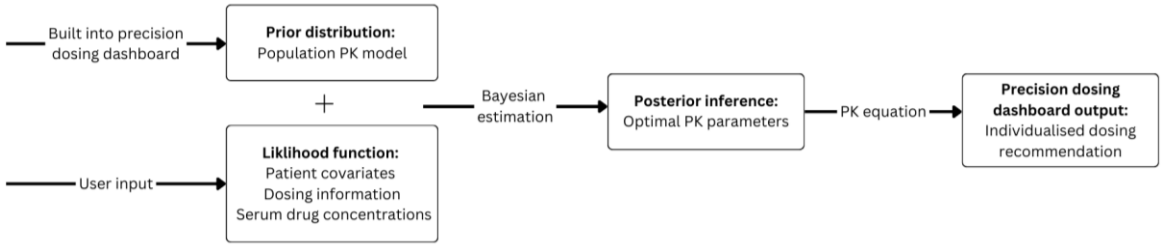
The drug target (e.g. average concentration, area under curve, trough concentration) was selected based on prior clinical research on the study drug (risankizumab) and patient population (psoriasis) (Khatri et al. 2020). The length of dosing interval (rather than dose magnitude) was selected as our dosing intervention.

Individualised patient PK parameters generated by the Bayesian model were extracted to calculate a personalised dosing interval from a PK equation to enable personalised dosing recommendations for future doses (Figure 6).

To develop the precision dosing dashboard, the final model and equations were integrated into a bespoke R Shiny interactive dashboard (version 1.7.5.1) (Chang et al.

2024). This was deployed on a secure cloud server hosted by King's College London. R and R Shiny are both free, open-source software with extensive online resources, facilitating accessibility and reproducibility. Within the dashboard, the user can enter up to three serum risankizumab concentration measurements per patient, the timing of the previous biologic dose and all patient covariates required for the PK model. Data inputted into the dashboard are not stored and no patient-identifiable data are used.

Figure 6: Workflow of personalised dosing estimation. PK; Pharmacokinetic



4.4 User testing of the precision dosing dashboard

The usability of the precision dosing dashboard was assessed in two user-testing workshops involving multidisciplinary healthcare professionals from multiple UK dermatology centres. Attendees were provided with a mock clinical scenario and invited to generate a personalised dose recommendation using the precision dosing dashboard. The time to generate the personalised dose recommendation was assessed and attendees shared feedback on the usability of the precision dosing dashboard in a survey. The survey included questions on dashboard user-friendliness, acceptability, and usability according to the System Usability Scale (SUS). The SUS, encompassing effectiveness, efficiency and satisfaction (Bangor et al. 2008), consists of 5 positive and 5 negative questions ranked according to a Likert scale: "strongly disagree" (1), "disagree" (2), "neutral" (3), "agree" (4), "strong agree" (5) (Brooke 1995). The SUS score was calculated by:

1. Subtract 1 from the user's rating for odd-numbered questions (positive).
2. Subtract the user's rating from 5 for even-numbered questions (negative).

3. This will give a score of 0-4 for each question.
4. Sum the numbers and multiply the total by 2.5.

This calculation provides a range of possible SUS scores from 0 to 100, where 68 is considered above average (Hyzy et al. 2022). Following user feedback, updates were made to the dashboard.

Data Availability Statement

The data presented in this study are available at the request of the corresponding author due to ethical and legal restrictions. The dashboard can be accessed at: *https://shiny-tdm.sites.er.kcl.ac.uk*.

Conflict of Interest

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