# Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis (POEMSLUN)

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Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis (POEMSLUN)

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Abstract

Background:
Mycophenolate sodium, an enteric-coated tablet (EC-MPS), is as effective and safe as mycophenolate mofetil (MMF) in preventing transplant rejection. EC-MPS and MMF improve the outcome of severe lupus nephritis (LN) and have fewer side effects than pulsed intravenous cyclophosphamide. Blood concentrations of mycophenolic acid (MPA), the active metabolite of EC-MPS, vary between participants despite fixed dosing. Interpatient variability has been studied in transplantation, but not well documented in LN. The relationship between MPA concentration and its clinical effect on LN has not been described.

Methods/Design:
This is a prospective, open-label, randomised controlled trial. Thirty two participants with LN who meet the inclusion and exclusion criteria will be randomised into two groups: one receiving a fixed dose of EC-MPS and the second, a dosing regimen that is titrated with therapeutic drug monitoring (TDM). Included participants will have blood sampled over a period of 8-12 hours on three different occasions. Pharmacokinetic parameters will be calculated using non-compartmental methods.

Discussion:
This study will determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure compared to standard empiric dosing in participants with biopsy proven LN. This study will show if there is a difference in the clinical outcome between participants on exposure controlled dose and fixed dose of MPS. By personalising MPS dosing for participants with LN using TDM, it may be possible to maximise therapeutic efficacy while preventing significant complications, therapeutic failure and toxicity. This study will validate the limited sampling strategy (LSS) for determining the area under curve (AUC) and evaluate the time needed for remission of LN.
Trial Registration: ACTRN12611000798965

Key words: Pharmacokinetics-Enteric coated Mycophenolate Sodium-Lupus Nephritis

Article Summary:

Article Focus:

- Interpatient variability of blood concentrations of mycophenolic acid (MPA), the active metabolite of enteric coated mycophenolate sodium (EC-MPS) has been studied in transplantation, but not well documented in Lupus Nephritis (LN).

- This article describes a protocol for a single center, open label, randomised controlled trial, using a two arm design to determine whether exposure guided dosing (therapeutic drug monitoring – TDM) of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure compared to fixed drug dosing in participants with LN.

Key Messages:

- This study will determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants in achieving established targets of MPA exposure compared to the standard fixed dosing in participants with biopsy proven LN.

- This study will also determine whether there is a difference in the complete and partial remission rates between participants on fixed drug dosing and exposure controlled dosing of MPS in LN in induction group and renal relapse in the maintenance group.

- This study will try to validate a limited blood sampling protocol to measure exposure to MPA using a 0-12 hour, 17 sample- based area under curve (AUC).

Strengths and limitations:

- This prospective randomised study is designed specifically to test whether exposure controlled dosing results in a higher proportion of participants achieves target exposure levels of MPA compared with exposure controlled dosing.

- Size of the sample studied will limit the power of observations.
**Background**

Mycophenolate mofetil (MMF), the first prodrug of mycophenolic acid (MPA), has been used in kidney transplant recipients for the prevention of acute rejection in combination with steroids and calcineurin inhibitors since 1995 in the USA and 1996 in Europe (1). A second MPA product, the enteric coated mycophenolate sodium (EC-MPS) became available subsequently. Clinical trials have shown that EC-MPS is therapeutically equivalent to MMF with comparable safety profiles and equimolar doses of the two drugs producing equivalent MPA exposures (2, 3). The favourable experience with MMF in transplant recipients resulted in it being used in trials involving participants with autoimmune and other immunologically mediated renal diseases (4, 5, 6, 7, 8). The Aspreva Lupus Management Study group (ALMS) found rates of adverse events, particularly infection, between MMF and intravenous cyclophosphamide to be similar in lupus nephritis (LN) (9). Furthermore, a recent meta-analysis of randomised controlled trials showed that MMF was superior in inducing remission in severe LN and had fewer side effects compared with pulsed cyclophosphamide (10). Other clinical trials reported similar results with EC-MPS (11, 12, 13, 14). The Therapeutic Goods Administration of Australia has approved EC-MPS-Myfortic® ([www.novartis.com.au/DownloadFile.aspx?t=p&f=myf.pdf](http://www.novartis.com.au/DownloadFile.aspx?t=p&f=myf.pdf)) for the treatment of classes III, IV, V and V LN (15).

**Dosing and therapeutic drug monitoring (TDM) of MMF/MPS**

MMF is usually administered at a fixed dose of 1000 mg twice daily in transplant recipients (independent of weight) and modified according to clinical tolerance. The randomised controlled trial, the Adaption de Posologie du MMF en Greffe Renale (APOMYGRE), and the fixed dose versus concentration controlled (FDCC) studies investigated the benefit of using TDM but results were not consistent (16, 17). APOMYGRE showed a reduction in acute rejection whereas the FDCC study had a neutral effect. To date, there is currently no consensus on using TDM of MPA to optimise MMF use in transplant patients (18, 19, 20, 21).
The dose of MMF for induction and maintenance therapy in LN varies from 2 to 3 gm a day (22). In the ALMS study, the median MMF dose was 42-mg/kg body weight by 20-24 weeks and 91.3% of participants tolerated daily doses of 2.5 to 3 gm daily (23). In a study by Petruck et al, 720 mg of MPS and 1000mg of MMF were found to deliver near equimolar exposures of MPA (24).

**Inter-individual variability of MPA**

Factors affecting the inter-patient variability of MPA have been extensively investigated in transplant recipients and are likely to be similar in LN (25, 26). The clearance of MPA depends on its non-protein bound fraction (26). Therefore, patients with reduced renal function and hypoalbuminemia have higher free fractions of MPA, theoretically resulting in higher MPA clearance and a lower MPA exposure. Furthermore, co-therapy with calcineurin inhibitors, phosphate binders, steroids and rifampicin may affect MPA pharmacokinetics (26). Nonetheless, the MPA concentration–effect relationship is more likely to be linear in LN patients treated with MMF and steroids, as opposed to transplant recipients who are treated with many immunosuppressive agents (27).

**TDM of MPA in LN**

Neumann et al. reported on the value of measuring MPA plasma concentrations in patients with autoimmune diseases (28, 29). In their study, there was a weak correlation between the 12-hour trough (C0) MPA concentrations and the area under the curve (AUC), with remission being associated with higher MPA trough concentrations (≥ 3.5 mg/L). There was a clustering of adverse events in participants with a high MPA exposure, thus refining the therapeutic window. In contrast, studies in renal transplant participants showed tolerability correlated poorly with MPA concentrations. Neumann et al proposed in their exploratory study that MPA trough levels
between 3.5 and 4.5 mg/L be used for maintenance of remission and prevention of adverse
events. Roland et al, in a prospective pharmacokinetic study of MMF in patients treated for
systemic lupus erythematosus, found a high inter–individual variability of MPA AUC levels (30).
The therapeutic range of MPA has to be better defined with the clinical response to exposure
controlled dosing in patients with LN.

*Limited Sample strategy (LSS)*

Measurement of AUC 0-12 hours has been well documented in transplant literature and a target
AUC 0-12 of 30mg/L/h to 60mg/L/h is advised to reduce the risk of rejection (31, 32). For
treatment with MMF, LSS was suggested as an alternative because MPA AUC 0-12 was
laborious and expensive (33, 34). LSS has been trialed for EC-MPS showing that time points from
the initial half of the full concentration time profile produced near identical results (35). Neuman et
al found that MPA exposure expressed as MPA AUC$_{0-12}$ was comparable in patients with
autoimmune diseases and renal transplant patients treated with EC-MPS (36). They suggested
an LSS for estimating MPA exposure could be valid in autoimmune disorders. A more recent
study using MPS by Fructuso et al suggested an AUC over 8 hours could be calculated with four
blood samples, correlating favourably with an AUC$_{0-12}$ (37).

Our study will include participants who have blood sampled over a period of 8 hours or 12 hours.
For the 8-hour sampling period, the AUC$_{0-12}$ will be calculated imputing the pre-dose sample value
for the 12-hour sample value. With few studies in LN treated with MPS formulations measuring the
relationship of MPA levels to efficacy and toxicity, this prospective randomised controlled trial will
add more information on the pharmacokinetics and pharmacodynamics of MPA in LN (38, 39).

**Aim**

This study is to determine whether TDM guided dosing of EC-MPS results in a higher proportion
of participants achieving targets of MPA exposure in LN compared to fixed drug dosing.

Methods/Design

Study design and setting

The study is a prospective, open-label, randomised controlled trial.

Participant population: Participants will be selected from either inpatients at Royal Brisbane and Women’s Hospital (RBWH) Renal and Rheumatology Departments or patients attending the Renal Rheumatology Lupus Vasculitis Clinic. This study will be done in collaboration with the Burns, Trauma and Critical Care Research Centre, School of Medicine, The University of Queensland and Department of Chemical Pathology, Pathology Queensland, Queensland Health.

The interventions will comprise of two groups:

*Intervention – Control*

Group 1: Fixed Dose Regime: oral EC-MPS 30mg/kg body weight to induce remission. MPS dosage will be reduced by 180 mg twice daily on achieving complete remission or if there are side effects such as diarrhea or leucopenia (total white cell count <3500/mm³ or opportunistic infections).

*Intervention – Experimental*

Group 2: Exposure Controlled dose: oral EC-MPS dose will be titrated according to the AUC\textsubscript{0-12} adjusted to a target AUC\textsubscript{0-12} of 40 to 60 mg/L/h. The dosage will be reduced if the AUC\textsubscript{0-12} is above 60 mg/L/h and once there is complete remission, an AUC of 30 to 50 mg/L/h will be maintained.

All participants in the control and intervention groups will undergo pharmacokinetic analysis of MPA.

Other than EC-MPS dosing, both groups will be given similar management of LN including...
treatment with corticosteroids. Below is an illustration of the study design:

(Figure 1. POEMSLUN study design)

**Identification of eligible participants**

Participants with biopsy proven Class III/IV/V LN who fulfill the inclusion and exclusion criteria are eligible for the study. The inclusion criterion has been kept as broad as possible to represent the participant population and the exclusion criteria as restricted as possible to maximise validity and generalisability of findings.

**Inclusion criteria**

All participants 18 years of age and above with Class III/IV/V LN proven by renal biopsy and have been on EC-MPS for more than two weeks either as maintenance or induction therapy will be eligible for this study.

**Exclusion criteria**

Participants will be excluded if there is a history of psychological illness, a condition which interferes with their ability to understand or comply with the requirements of the study or who are unable to give consent. Pregnant, nursing (lactating) women and women planning on getting pregnant during the study period and not using contraception will be excluded. Finally, those with a history of malignancy treated or untreated within the past 5 years (with the exception of localized basal or squamous cell carcinomas of the skin) regardless of local recurrence or metastases will also be excluded from the study.

**Participants**

Participants are randomised in permuted block sizes of 2 and 4 with the percent 33 and 66
respectively and stratified for induction and maintenance therapy with EC-MPS. Masking of investigators and participants will not be possible. Nonetheless, the laboratory staff analysing the pharmacokinetics of MPS will be masked to the treatment allocation. An individual’s participation in the study will cease at the end of the study period, which will be 12 months after the last participant is recruited. The recruitment period is 36 months. It is anticipated that the average follow-up time will be 24 months, assuming a steady recruitment rate of 12 participants per year.

Outcome measures

Primary

This is a study to determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving established targets of MPA exposure compared to the standard empirical dosing in participants with biopsy proven LN.

Secondary

This study will also determine whether there is a difference in the complete and partial remission rates between participants on fixed drug dosing and exposure controlled dosing of MPS in LN in induction group and renal relapse in the maintenance group.

Complete remission is defined as a decrease in urinary protein measured over 24 hours to less than 0.5 g/24 h, a urine protein/creatinine ratio (uPCR) of less than 0.5 mg/mg (50 mmol/mg) with a normal urinary sediment, normal serum albumin and stabilisation (± 25%) or improvement in serum creatinine levels at week 24 from the first sample. Partial remission is defined as stabilisation (± 25%) or improved renal function (but still not to normal with reduction of proteinuria by more than 50% ranging between 0.3 to 3g/24h and a serum albumin of more than 30g/L (40). Renal relapse is defined as “recrudescence of renal disease after an initial response demonstrated by a recent increase in serum creatinine by >50% with active urinary sediment and or increase in proteinuria to 3.5 g/day or greater” (41). Proteinuria will be measured using the
urine protein to creatinine ratio or by measuring the 24-hour urinary protein excretion. The urine protein to creatinine ratio is numerically equal to 24-hour urinary protein excretion in grams.

Secondary outcome measures include the time required to achieve complete or partial remission, the assessment of improvement with the SLE Disease Activity Index (SLEDAI) score as well as C3, C4 and anti-dsDNA levels, the development of a pharmacokinetic model that can be used to develop MPS dosing recommendations in LN participants treated with MPS, validating the LSS for determining $\text{AUC}_{0-12}$, and the evaluation of the cost effectiveness of TDM analysis of MPS. An individual who is masked to the study allocation and not involved in the clinical care of the participant will adjudicate outcome measures.

Data Collection
Clinical and demographic data are collected for each participant, including age, gender, weight, height, allergies, clinical information, other co-morbidities, concomitantly prescribed drugs, serious adverse events, safety and treatment outcomes (clinical and/or immunological improvement) including SLEDAI scores. (Table I)

Laboratory investigations are performed consisting of renal function assessments, urine sediment examination, 24 hour urinary protein and creatinine measurement, eGFR (Modification of Diet in Renal Disease-GFR(mL/min/1.73 m2) = 175 × (S. Cr)-1.154 × (Age)-0.203 × (0.742 if female) × (1.212 if African American) (conventional units) (42)), liver function tests, complement components C3 and C4, antinuclear antibody (ANA), anti-double stranded DNA and pharmacokinetic analysis of mycophenolic acid (MPA).

The above information will be collected every 12 weeks and the presence of any serious adverse effects will be continually monitored and recorded during the study period. It is anticipated that the
average follow-up time will be 18 months assuming a constant recruitment rate.

**Data analysis**

Blood samples will be collected by a dedicated research nurse at 15 time points for the 8 hour group and 17 samples for the 12 hour group, including the time points from previously described LSS data for mycophenolate sodium at 0, 1.5, 4 and 8 hours post-dose, on three different occasions. Blood samples for the 8-hour group will be collected at half hourly intervals initially until 7-hours and the last sample at the 8th hour. Blood samples for the 12-hour group will be collected as for the 8-hour group along with further samples at the 10th and 12th hour. Samples will be kept on ice until centrifugation (3000 rpm for 10-minutes) and will then be analysed by High Performance Liquid Chromatography at Pathology Queensland (Royal Brisbane and Women’s Hospital, Herston, Australia).

**Induction Phase:** Blood sampling at three different time points; first sample at 1 to 2 months, second at 3 to 4 months and the third at 7 to 9 months.

**Maintenance Phase:** Pharmacokinetic study will be done only once at the time of entry. The pharmacokinetic values will be calculated using non-compartmental methods. The AUC_{0-12} will be calculated using the trapezoidal rule; CL = Dose/AUC; Cmax will be the observed value; apparent terminal elimination rate constant (λz) will be determined from log-linear least squares regression analysis of concentrations from 4-8 hours. Vz = CL/ λz; apparent elimination half-life = \ln (2)/ λz.

**Statistical methods**

A sample size of 32 participants is projected with 16 in each group. The sample required to test the ability for TDM guided dosing to achieve target MPS exposure compared with no TDM, is based on pharmacokinetic data from patients with lupus nephritis by Lertdumrongluk et al (43). Using a 95% confidence interval, predicting that 50% of patients will have exposures under the
target range requires a total sample of 30 participants. We will collect data from 32 assuming there is less than a 10% attrition rate (44).

Comparisons between groups for the outcome variable for complete and partial remission will be performed using Chi Square or Fisher’s exact tests followed by a multivariable logistic regression analysis to estimate the association between outcome and the groups. The secondary outcome of interest, namely, time to complete/partial remission will be evaluated using Kaplan-Meier survival curves, log-rank test. Multivariable Cox regression models will be used to estimate the effect of group adjusting for other covariates. Student T-test or Mann-Whitney U test are used to compare the continuous variables. Differences in infection rates (number of infections/total follow-up time) and serious adverse events between the 2 groups will be analysed by Z tests. All data will be analysed on an intention-to-treat basis, and a significance level of 0.05 will be assumed.

**Ethical considerations and dissemination**

The Human Research and Ethics Committee of the RBWH have approved this study. The investigators will comply with and conduct the study in accordance with Good Clinical Practice Guidelines, the principles that have their origins in the “Declaration of Helsinki” adopted by the World Medical Association in October 1996, the NHMRC National Statement on Ethical Conduct in Human Research (2007) or replacement, and or other relevant NHMRC publication or guideline that relate or may relate to clinical trials (45).

Withdrawal of study medication may be made at the discretion of the investigator following a serious adverse event. However, participants will continue to be followed for the duration of the study if possible, even if they have stopped treatment. This will include attendance at scheduled trial visits, and data collection, particularly of outcomes. The investigator may withdraw a participant from study medication at any time if it is felt to be in the best interests of the participant. Under such circumstances, participants will continue to be monitored for outcome events and will
attend scheduled trial visits so that results can be analysed on an intention to treat basis. If a participant withdraws consent for the study they shall be withdrawn from the study. Any participant is free to withdraw their consent at any time without the need to justify their decision. We plan to publish the results in medical journals and present the de-identified information at conferences.

Discussion

Several studies have demonstrated that MMF/MPS is effective at gaining control of severe LN. The variations in pharmacokinetics of MPA/MPS and the factors causing these differences have been studied in transplant recipients but are not well documented in those with LN. The primary objective of this study is to examine whether exposure controlled MPS dosing results in higher proportion of participants achieving targets of MPA exposure compared to standard empiric dosing in participants with LN. Secondary objectives include the efficacy of exposure controlled MPS dosing in LN with TDM, the relationship between the disease activity of LN and MPA blood concentrations (pharmacodynamics), and using the data to develop dosing recommendations for MPS in LN. Defining the optimal therapeutic range for MPA is likely to help improve outcomes in participants with LN treated with MPS. The consequences of failure of immunosuppression in LN can be severe and can lead to end stage renal failure. By personalising MPS dosing for participants with LN using TDM, it may be possible to maximise therapeutic efficacy while preventing significant complications, therapeutic failure and toxicity.
Author contributions

DR, GJ and JR designed the study and wrote the protocol. DR is the Principal investigator and JR and GJ are equal senior authors. HH, JL and RGF provided advice reviewed the study protocol and ethics application. PK provided input and will be involved with the recruitment component of the study. JR, JU and BMcW will be involved in the analysis of samples. AL, MLP, MR, and RR will be involved in the collection of blood samples and data collection. AL assisted in preparing the manuscript. All authors read and approved the final manuscript.

Competing interests:

DR and GJ were principal investigators for Ascertain study sponsored by Novartis Australia (pte) limited and Novartis India (pte) limited respectively.

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For peer review only - [Link to guidelines]

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Figure 1. POEMSLUN study design

Pharmacokinetics of Mycophenolate Sodium (MPS) in Lupus Nephritis

Randomisation – Stratification: Induction and Maintenance

Induction: MPS 30mg/kg B W

Monitor AUC
1 sample: 4-6 weeks
2 sample: 14-16 weeks

AUC driven dose 40-60 mgH/L

Remission in 6 months

NO

Reduce by 180mg b.d.

YES

Maintenance Phase
Monitor AUC 3rd sample: 28-32 weeks

Drop Out
- Treatment failure
- Unachievable remission
- Drug failure or intolerance requiring alternative agents
- Non compliance

Remission in 6 months

NO

YES

Maintenance Dose:
Reduce dose by 180mg b.d. and adjust to AUC 30-50mgH/L
### Table 1: Visit schedule

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<thead>
<tr>
<th>Test</th>
<th>Study Visit</th>
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<td>1 (Baseline)</td>
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<td>Pharmacokinetic analysis -Total 3 sampling occasions*</td>
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List of abbreviations

POEMSLUN - Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis

EC-MPS- Enteric coated Mycophenolate sodium

MMF- Mycophenolate mofetil

LN - lupus nephritis

MPA - mycophenolic acid

TDM- therapeutic drug monitoring

LSS - limited sampling strategy

SLE - systemic lupus erythematosus

S. Cr- Serum creatinine

uPCR - urine protein/creatinine ratio

SLEDAI - SLE Disease Activity Index
Pharmacokinetics of Mycophenolate Sodium in Lupus Nephritis

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| Medical history | X | X | X | X | X |
| Clinical assessment | X | X | X | X | X |
| SLEDAI assessment | X | X | X | X | X |
| Renal Function assessment | X | X | X | X | X |
| Immunological Study | X | X | X | X | X |
| Adverse event assessment | X | X | X | X | X |
| Pharmacokinetic analysis -Total 3 sampling occasions* – | ☀ | ☀ | ☀ | ☀ | ☀ |
**A Protocol for the Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis (POEMSLUN)- an Open-label, Randomised Controlled Trial.**

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<td>Secondary Subject Heading:</td>
<td>Research methods</td>
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<tr>
<td>Keywords:</td>
<td>Lupus Nephritis, Mycophenolate Sodium, Pharmacokinetics</td>
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A Protocol for the Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis (POEMSLUN)- an open-label, Randomised Controlled Trial.

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Abstract

Background:
Mycophenolate sodium, an enteric-coated tablet (EC-MPS), is as effective and safe as mycophenolate mofetil (MMF) in preventing transplant rejection. EC-MPS and MMF improve the outcome of severe lupus nephritis (LN) and have fewer side effects than pulsed intravenous cyclophosphamide. Blood concentrations of mycophenolic acid (MPA), the active metabolite of EC-MPS, vary between participants despite fixed dosing. Interpatient variability has been studied in transplantation, but not well documented in LN. The relationship between MPA concentration and its clinical effect on LN has not been described.

Methods/Design:
This is a prospective, open-label, randomised controlled trial. Thirty two participants with LN who meet the inclusion and exclusion criteria will be randomised into two groups: one receiving a fixed dose of EC-MPS and the second, a dosing regimen that is titrated with therapeutic drug monitoring (TDM). Included participants will have blood sampled over a period of 8-12 hours on three different occasions. Pharmacokinetic parameters will be calculated using non-compartmental methods.

Discussion:
This study will determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure compared to standard empiric dosing in participants with biopsy proven LN. This study will show if there is a difference in the clinical outcome between participants on exposure controlled dose and fixed dose of MPS. By personalising MPS dosing for participants with LN using TDM, it may be possible to maximise therapeutic efficacy while preventing significant complications, therapeutic failure and toxicity. This study will validate the limited sampling strategy (LSS) for determining the area under curve
(AUC) and evaluate the time needed for remission of LN.

**Trial Registration:** ACTRN12611000798965

**Key words:** Pharmacokinetics-Enteric coated Mycophenolate Sodium-Lupus Nephritis

**Article Summary:**

**Article Focus:**

- Interpatient variability of blood concentrations of mycophenolic acid (MPA), the active metabolite of enteric coated mycophenolate sodium (EC-MPS) has been studied in transplantation, but not well documented in Lupus Nephritis (LN).

- This article describes a protocol for a single center, open label, randomised controlled trial, using a two arm design to determine whether exposure guided dosing (therapeutic drug monitoring –TDM) of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure compared to fixed drug dosing in participants with LN.

**Key Messages:**

- This study will determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants in achieving established targets of MPA exposure compared to the standard fixed dosing in participants with biopsy proven LN.

- This study will also determine whether there is a difference in the complete and partial remission rates between participants on fixed drug dosing and exposure controlled dosing of MPS in LN in induction group and renal relapse in the maintenance group.

- This study will try to validate a limited blood sampling protocol to measure exposure to MPA using a 0-12 hour, 17 sample- based area under curve (AUC)

**Strengths and limitations:**

- This prospective randomised study is designed specifically to test whether exposure controlled dosing results in a higher proportion of participants achieves target exposure levels of MPA compared with exposure controlled dosing.
• Size of the sample studied will limit the power of observations.

Background

Mycophenolate mofetil (MMF), the first prodrug of mycophenolic acid (MPA), has been used in kidney transplant recipients for the prevention of acute rejection in combination with steroids and calcineurin inhibitors since 1995 in the USA and 1996 in Europe (1). A second MPA product, the enteric coated mycophenolate sodium (EC-MPS) became available subsequently. Clinical trials have shown that EC-MPS is therapeutically equivalent to MMF with comparable safety profiles and equimolar doses of the two drugs producing equivalent MPA exposures (2, 3). The favourable experience with MMF in transplant recipients resulted in it being used in trials involving participants with autoimmune and other immunologically mediated renal diseases (4, 5, 6, 7, 8). The Aspreva Lupus Management Study group (ALMS) found rates of adverse events, particularly infection, between MMF and intravenous cyclophosphamide to be similar in lupus nephritis (LN) (9). Furthermore, a recent meta-analysis of randomised controlled trials showed that MMF was superior in inducing remission in severe LN and had fewer side effects compared with pulsed cyclophosphamide (10). Other clinical trials reported similar results with EC-MPS (11, 12, 13, 14). The Therapeutic Goods Administration of Australia has approved EC-MPS-Myfortic® (www.novartis.com.au/DownloadFile.aspx?i=p&f=myf.pdf) for the treatment of classes III, IV, V and V LN (15).

Dosing and therapeutic drug monitoring (TDM) of MMF/MPS

MMF is usually administered at a fixed dose of 1000 mg twice daily in transplant recipients (independent of weight) and modified according to clinical tolerance. The randomised controlled trial, the Adaption de Posologie du MMF en Greffe Renale (APOMYGRE), and the fixed dose versus concentration controlled (FDCC) studies investigated the benefit of using TDM but results were not consistent (16, 17). APOMYGRE showed a reduction in acute rejection whereas the FDCC study had a neutral effect. To date, there is currently no consensus on using TDM of MPA.
to optimise MMF use in transplant patients (18, 19, 20, 21).

The dose of MMF for induction and maintenance therapy in LN varies from 2 to 3 gm a day (22).

In the ALMS study, the median MMF dose was 42-mg/kg body weight by 20-24 weeks and 91.3% of participants tolerated daily doses of 2.5 to 3 gm daily (23). In a study by Petruck et al, 720 mg of MPS and 1000mg of MMF were found to deliver near equimolar exposures of MPA (24).

Inter-individual variability of MPA

Factors affecting the inter-patient variability of MPA have been extensively investigated in transplant recipients and are likely to be similar in LN (25, 26). The clearance of MPA depends on its non-protein bound fraction (26). Therefore, patients with reduced renal function and hypoalbuminemia have higher free fractions of MPA, theoretically resulting in higher MPA clearance and a lower MPA exposure. Furthermore, co-therapy with calcineurin inhibitors, phosphate binders, steroids and rifampicin may affect MPA pharmacokinetics (26). Nonetheless, the MPA concentration–effect relationship is more likely to be linear in LN patients treated with MMF and steroids, as opposed to transplant recipients who are treated with many immunosuppressive agents (27).

TDM of MPA in LN

Neumann et al. reported on the value of measuring MPA plasma concentrations in patients with autoimmune diseases (28, 29). In their study, there was a weak correlation between the 12-hour trough (C0) MPA concentrations and the area under the curve (AUC), with remission being associated with higher MPA trough concentrations (≥ 3.5 mg/L). There was a clustering of adverse events in participants with a high MPA exposure, thus refining the therapeutic window. In contrast, studies in renal transplant participants showed tolerability correlated poorly with MPA.
concentrations. Neumann et al proposed in their exploratory study that MPA trough levels between 3.5 and 4.5 mg/L be used for maintenance of remission and prevention of adverse events. Roland et al, in a prospective pharmacokinetic study of MMF in patients treated for systemic lupus erythematosus, found a high inter-individual variability of MPA AUC levels (30). The therapeutic range of MPA has to be better defined with the clinical response to exposure controlled dosing in patients with LN.

Limited Sample strategy (LSS)

Measurement of AUC 0-12 hours has been well documented in transplant literature and a target AUC 0-12 of 30mg/L/h to 60mg/L/h is advised to reduce the risk of rejection (31, 32). For treatment with MMF, LSS was suggested as an alternative because MPA AUC 0-12 was laborious and expensive (33, 34). LSS has been trialed for EC-MPS showing that time points from the initial half of the full concentration time profile produced near identical results (35). Neuman et al found that MPA exposure expressed as MPA AUC$_{0-12}$ was comparable in patients with autoimmune diseases and renal transplant patients treated with EC-MPS (36). They suggested an LSS for estimating MPA exposure could be valid in autoimmune disorders. A more recent study using MPS by Fructuso et al suggested an AUC over 8 hours could be calculated with four blood samples, correlating favourably with an AUC$_{0-12}$ (37).

Our study will include participants who have blood sampled over a period of 8 hours or 12 hours. For the 8-hour sampling period, the AUC$_{0-12}$ will be calculated imputing the pre-dose sample value for the 12-hour sample value. With few studies in LN treated with MPS formulations measuring the relationship of MPA levels to efficacy and toxicity, this prospective randomised controlled trial will add more information on the pharmacokinetics and pharmacodynamics of MPA in LN (38, 39).

Aim
This study is to determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure in LN compared to fixed drug dosing.

**Methods/Design**

**Study design and setting**

The study is a prospective, open-label, randomised controlled trial.

Participant population: Participants will be selected from either inpatients at Royal Brisbane and Women’s Hospital (RBWH) Renal and Rheumatology Departments or patients attending the Renal Rheumatology Lupus Vasculitis Clinic. This study will be done in collaboration with the Burns, Trauma and Critical Care Research Centre, School of Medicine, The University of Queensland and Department of Chemical Pathology, Pathology Queensland, Queensland Health.

The interventions will comprise of two groups:

**Intervention – Control**

Group 1: Fixed Dose Regime: oral EC-MPS 30mg/kg body weight to induce remission. MPS dosage will be reduced by 180 mg twice daily on achieving complete remission or if there are side effects such as diarrhea or leucopenia (total white cell count <3500/mm$^3$ or opportunistic infections).

**Intervention – Experimental**

Group 2: Exposure Controlled dose: oral EC-MPS dose will be titrated according to the $AUC_{0-12}$ adjusted to a target $AUC_{0-12}$ of 40 to 60 mg/L/h. The dosage will be reduced if the $AUC_{0-12}$ is above 60 mg/L/h and once there is complete remission, an AUC of 30 to 50 mg/L/h will be maintained.

All participants in the control and intervention groups will undergo pharmacokinetic analysis of MPA.
Other than EC-MPS dosing, both groups will be given similar management of LN including treatment with corticosteroids. Below is an illustration of the study design:

(Figure 1. POEMSLUN study design)

Pharmacokinetics of Mycophenolate Sodium in Lupus Nephritis

Identification of eligible participants

Participants with biopsy proven Class III/IV/V LN who fulfill the inclusion and exclusion criteria are eligible for the study. The inclusion criterion has been kept as broad as possible to represent the participant population and the exclusion criteria as restricted as possible to maximise validity and generalisability of findings.

Inclusion criteria

All participants 18 years of age and above with Class III/IV/V LN proven by renal biopsy and have been on EC-MPS for more than two weeks either as maintenance or induction therapy will be eligible for this study.

Exclusion criteria

Participants will be excluded if there is a history of psychological illness, a condition which interferes with their ability to understand or comply with the requirements of the study or who are unable to give consent. Pregnant, nursing (lactating) women and women planning on getting pregnant during the study period and not using contraception will be excluded. Finally, those with a history of malignancy treated or untreated within the past 5 years (with the exception of localized basal or squamous cell carcinomas of the skin) regardless of local recurrence or metastases will also be excluded from the study.
Informed Consent:
At the recommendation of the treating clinician who will seek permission from the participant or
authorised surrogate to be approached by the investigator, the investigator/s will seek informed
consent or assent from potential trial participants or authorised surrogate. This will occur through
a verbal presentation of the written consent document, which the participant or authorised
surrogate would then be given sufficient time to consider before consenting to the study or not.

Participants
Participants are randomised in permuted block sizes of 2 and 4 with the percent 33 and 66
respectively and stratified for induction and maintenance therapy with EC-MPS. Masking of
investigators and participants will not be possible. Nonetheless, the laboratory staff analysing the
pharmacokinetics of MPS will be masked to the treatment allocation. An individual’s participation
in the study will cease at the end of the study period, which will be 12 months after the last
participant is recruited. The recruitment period is 36 months. It is anticipated that the average
follow-up time will be 24 months, assuming a steady recruitment rate of 12 participants per year.
The participants will have regular clinic appointments and follow up to improve adherence. A trial
pharmacist will be involved with the study and will detail the changes in medication doses and
monitor participant adherence.

Adverse Events:
Adverse events are defined as any untoward medical event (clinical or laboratory) experienced by
a participant during the course of this clinical trial and considered by the investigator to be related
to the study. All adverse events will be recorded on the Adverse Event page of the case report
form and reported immediately to the Human Research and Ethics Committee (HREC) in writing.

Adverse events will be reported from the day of consent. The responsible investigator will
determine whether the degree of any untoward event warrants removal of any participant from the
study. He/she will institute appropriate diagnostic and therapeutic measures and keep the participant under observation for as long as is medically indicated.

Outcome measures

Primary

This is a study to determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving established targets of MPA exposure compared to the standard empirical dosing in participants with biopsy proven LN.

Secondary

This study will also determine whether there is a difference in the complete and partial remission rates between participants on fixed drug dosing and exposure controlled dosing of MPS in LN in induction group and renal relapse in the maintenance group.

Complete remission is defined as a decrease in urinary protein measured over 24 hours to less than 0.3 g/24 h, a urine protein/creatinine ratio (uPCR) of less than 0.3 mg/mg (30 mmol/mg) with a normal urinary sediment, normal serum albumin and stabilisation (± 25%) or improvement in serum creatinine levels at week 24 from the first sample. Partial remission is defined as stabilisation (± 25%) or improved renal function (but still not to normal with reduction of proteinuria by more than 50% ranging between 0.3 to 3g/24h and a serum albumin of more than 30g/L (40). Renal relapse is defined as “recrudescence of renal disease after an initial response demonstrated by a recent increase in serum creatinine by >50% with active urinary sediment and or increase in proteinuria to 3.5 g/day or greater” (41). Proteinuria will be measured using the urine protein to creatinine ratio or by measuring the 24-hour urinary protein excretion. The urine protein to creatinine ratio is numerically equal to 24-hour urinary protein excretion in grams.

Secondary outcome measures include the time required to achieve complete or partial remission,
the assessment of improvement with the SLE Disease Activity Index (SLEDAI) score as well as C3, C4 and anti-dsDNA levels, the development of a pharmacokinetic model that can be used to develop MPS dosing recommendations in LN participants treated with MPS, validating the LSS for determining \( \text{AUC}_{0-12} \), and the evaluation of the cost effectiveness of TDM analysis of MPS. An individual who is masked to the study allocation and not involved in the clinical care of the participant will adjudicate outcome measures.

**Data Collection**

Clinical and demographic data are collected for each participant, including age, gender, weight, height, allergies, clinical information, other co-morbidities, concomitantly prescribed drugs, serious adverse events, safety and treatment outcomes (clinical and/or immunological improvement) including SLEDAI scores. (Table I)

Laboratory investigations are performed consisting of renal function assessments, urine sediment examination, 24 hour urinary protein and creatinine measurement, eGFR (Modification of Diet in Renal Disease-GFR\((\text{mL/min/1.73 m2}) = 175 \times (S. \text{Cr})^{-1.154} \times (\text{Age})^{-0.203} \times (0.742 \text{ if female}) \times (1.212 \text{ if African American}) \text{ (conventional units) (42)})\), liver function tests, complement components C3 and C4, antinuclear antibody (ANA), anti-double stranded DNA and pharmacokinetic analysis of mycophenolic acid (MPA).

The above information will be collected every 12 weeks and the presence of any serious adverse effects will be continually monitored and recorded during the study period. It is anticipated that the average follow-up time will be 18 months assuming a constant recruitment rate.

**Data analysis**

Blood samples will be collected by a dedicated research nurse at 15 time points for the 8 hour
group and 17 samples for the 12 hour group, including the time points from previously described LSS data for mycophenolate sodium at 0, 1.5, 4 and 8 hours post-dose, on three different occasions. Blood samples for the 8-hour group will be collected at half hourly intervals initially until 7-hours and the last sample at the 8th hour. Blood samples for the 12-hour group will be collected as for the 8-hour group along with further samples at the 10th and 12th hour. Samples will be kept on ice until centrifugation (3000 rpm for 10-minutes) and will then be analysed by High Performance Liquid Chromatography at Pathology Queensland (Royal Brisbane and Women’s Hospital, Herston, Australia).

Induction Phase: Blood sampling at three different time points; first sample at 1 to 2 months, second at 3 to 4 months and the third at 7 to 9 months.

Maintenance Phase: Pharmacokinetic study will be done only once at the time of entry. The pharmacokinetic values will be calculated using non-compartmental methods. The $AUC_{0-12}$ will be calculated using the trapezoidal rule; $CL = \text{Dose} / AUC$; $Cmax$ will be the observed value; apparent terminal elimination rate constant ($\lambda_z$) will be determined from log-linear least squares regression analysis of concentrations from 4-8 hours. $Vz = CL / \lambda_z$; apparent elimination half-life $= \ln (2) / \lambda_z$.

**Statistical methods**

A sample size of 32 participants is projected with 16 in each group. The sample required to test the ability for TDM guided dosing to achieve target MPS exposure compared with no TDM, is based on pharmacokinetic data from patients with lupus nephritis by Lertdumrongluk et al (43).

Using a 95% confidence interval, predicting that 50% of patients will have exposures under the target range requires a total sample of 30 participants. We will collect data from 32 assuming there is less than a 10% attrition rate (44).

Comparisons between groups for the outcome variable for complete and partial remission will be performed using Chi Square or Fisher’s exact tests followed by a multivariable logistic regression.
analysis to estimate the association between outcome and the groups. The secondary outcome of interest, namely, time to complete/partial remission will be evaluated using Kaplan-Meier survival curves, log-rank test. Multivariable Cox regression models will be used to estimate the effect of group adjusting for other covariates. Student T-test or Mann-Whitney U test are used to compare the continuous variables. Differences in infection rates (number of infections/total follow-up time) and serious adverse events between the 2 groups will be analysed by Z tests. All data will be analysed on an intention-to-treat basis, and a significance level of 0.05 will be assumed.

**Ethical considerations and dissemination**

The Human Research and Ethics Committee of the RBWH have approved this study. The investigators will comply with and conduct the study in accordance with Good Clinical Practice Guidelines, the principles that have their origins in the “Declaration of Helsinki” adopted by the World Medical Association in October 1996, the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research (2007) or replacement, and or other relevant NHMRC publication or guideline that relate or may relate to clinical trials (45).

Withdrawal of study medication may be made at the discretion of the treating physician or investigator following an adverse event. However, participants will continue to be followed for the duration of the study if possible, even if they have stopped treatment. This will include attendance at scheduled trial visits, and data collection, particularly of outcomes. The investigator may withdraw a participant from study medication at any time if it is felt to be in the best interests of the participant, where there is disease progression or non-adherence to study medication. Under such circumstances, participants will continue to be monitored for outcome events and will attend scheduled trial visits so that results can be analysed on an intention to treat basis. If a participant withdraws consent for the study they shall be withdrawn from the study. Any participant is free to withdraw their consent at any time without the need to justify their decision.
We plan to publish the results in medical journals and present the de-identified information at conferences.

**Protection of participant confidentiality**

Participants’ records and the data generated by the study will be confidential in line with the recommendations of the Australian NHMRC and locally applicable laws. Standardized case report forms will be provided for each participant on this study. The participants in this study will be identified only by initials and subject number on these forms. Any information that may identify a participant will be excluded from data presented in the public arena. Data will only be shared among the investigators. Individual participant’s medical information may be given to the treating clinician where deemed clinically necessary. De-identified information will not be released. Data collected as part of this trial will be stored on a computer data base held by the principal investigator in a secure, lockable location. The data will be stored for 15 years after completion of the project in accordance with the revision of the Joint NHMRC/ Australian Vice Chancellors’ Committee (AVCC) statement and guidelines on research practice (45).

**Discussion**

Several studies have demonstrated that MMF/MPS is effective at gaining control of severe LN. The variations in pharmacokinetics of MPA/MPS and the factors causing these differences have been studied in transplant recipients but are not well documented in those with LN. The primary objective of this study is to examine whether exposure controlled MPS dosing results in higher proportion of participants achieving targets of MPA exposure compared to standard empiric dosing in participants with LN. Secondary objectives include the efficacy of exposure controlled MPS dosing in LN with TDM, the relationship between the disease activity of LN and MPA blood concentrations (pharmacodynamics), and using the data to develop dosing recommendations...
for MPS in LN. Defining the optimal therapeutic range for MPA is likely to help improve outcomes in participants with LN treated with MPS. The consequences of failure of immunosuppression in LN can be severe and can lead to end stage renal failure. By personalising MPS dosing for participants with LN using TDM, it may be possible to maximise therapeutic efficacy while preventing significant complications, therapeutic failure and toxicity.

Current status of the study

The study has commenced and is in its early stages. The recruitment rate will be assessed periodically and if the target is unlikely to be met, we will invite other nephrology centers in Queensland to participate in the study.

Author contributions

DR, GJ and JR designed the study and wrote the protocol. DR is the Principal investigator and JR and GJ are equal senior authors. HH, JL and RGF provided advice reviewed the study protocol and ethics application. PK provided input and will be involved with the recruitment component of the study. JR, JU and BMcW will be involved in the analysis of samples. AL, MLP, MR, and RR will be involved in the collection of blood samples and data collection. AL assisted in preparing the manuscript. All authors read and approved the final manuscript.

Competing interests:

DR and GJ were principal investigators for Ascertain study sponsored by Novartis Australia (pte) limited and Novartis India (pte) limited respectively.

Funding statement:
This study is funded by a Research grant from the RBWH Research Foundation and an unrestricted grant Novartis Australia. The study funders have no role in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication. The investigators will have ultimate authority over each of these activities.

**Acknowledgements**

We thank Drs. Sree Krishna Venthurupalli and Jennifer Martin, members of Data Safety monitoring board and Dr Shankar Viswanathan for advice on statistical methods.

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  12-hour trough levels and clinical endpoints in participants with autoimmune disease 

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  of mycophenolic acid area under the curve in adult renal transplant participants 


Figure 1. POEMSLUN study design

Pharmacokinetics of Mycophenolate Sodium (MPS) in Lupus Nephritis

Randomisation – Stratification: Induction and Maintenance

Induction: MPS 30mg/kg B.W

Fixed Dose

Monitor AUC
1 sample: 4-6 weeks
2 sample: 14-16 weeks

AUC driven dose 40-60 mgH/L

Remission in 6 months NO

YES

Reduce by 180mg b.d.

Remission in 6 months NO

YES

Drop Out
- Treatment failure
- Unachievable remission
- Drug failure or intolerance requiring alternative agents
- Non compliance

Maintenance Phase
Monitor AUC 3rd sample: 26-32 weeks

Maintenance Dose:
Reduce dose by 160mg b.d. and adjust to AUC 30-50mgH/L
### Table 1: Visit schedule

<table>
<thead>
<tr>
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<th>Study Visit</th>
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<tr>
<td></td>
<td>1 (Baseline)</td>
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<td></td>
<td>2 (4-6 weeks)</td>
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<td>3 (12th week)</td>
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<td>4 (14-16 weeks)</td>
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<td>7 (28-32 weeks)</td>
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<td>8 (36th week)</td>
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<td>End of study (48th week)</td>
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| Demographics            | X   |
| Medical history         | X   |
| Clinical assessment     | X   |
| SLEDAI assessment       | X   |
| Renal Function assessment| X   |
| Immunological Study     | X   |
| Adverse event assessment| X   |
Pharmacokinetic analysis -Total 3 sampling occasions* –

List of abbreviations

POEMSLUN - Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis

EC-MPS- Enteric coated Mycophenolate sodium

MMF- Mycophenolate mofetil

LN - lupus nephritis

MPA - mycophenolic acid

TDM- therapeutic drug monitoring

LSS - limited sampling strategy

SLE - systemic lupus erythematosus

S. Cr- Serum creatinine

uPCR - urine protein/creatinine ratio

SLEDAI - SLE Disease Activity Index

NHMRC- National Health and Medical Research Council
A Protocol for the Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis (POEMSLUN) - an open-label, Randomised Controlled Trial.

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Abstract

Background:
Mycophenolate sodium, an enteric-coated tablet (EC-MPS), is as effective and safe as mycophenolate mofetil (MMF) in preventing transplant rejection. EC-MPS and MMF improve the outcome of severe lupus nephritis (LN) and have fewer side effects than pulsed intravenous cyclophosphamide. Blood concentrations of mycophenolic acid (MPA), the active metabolite of EC-MPS, vary between participants despite fixed dosing. Interpatient variability has been studied in transplantation, but not well documented in LN. The relationship between MPA concentration and its clinical effect on LN has not been described.

Methods/Design:
This is a prospective, open-label, randomised controlled trial. Thirty two participants with LN who meet the inclusion and exclusion criteria will be randomised into two groups: one receiving a fixed dose of EC-MPS and the second, a dosing regimen that is titrated with therapeutic drug monitoring (TDM). Included participants will have blood sampled over a period of 8-12 hours on three different occasions. Pharmacokinetic parameters will be calculated using non-compartmental methods.

Discussion:
This study will determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure compared to standard empiric dosing in participants with biopsy proven LN. This study will show if there is a difference in the clinical outcome between participants on exposure controlled dose and fixed dose of MPS. By personalising MPS dosing for participants with LN using TDM, it may be possible to maximise therapeutic efficacy while preventing significant complications, therapeutic failure and toxicity. This study will validate the limited sampling strategy (LSS) for determining the area under curve
(AUC) and evaluate the time needed for remission of LN.

**Trial Registration:** ACTRN12611000798965

**Key words:** Pharmacokinetics-Enteric coated Mycophenolate Sodium-Lupus Nephritis

**Article Summary:**

**Article Focus:**

- Interpatient variability of blood concentrations of mycophenolic acid (MPA), the active metabolite of enteric coated mycophenolate sodium (EC-MPS) has been studied in transplantation, but not well documented in Lupus Nephritis (LN).
- This article describes a protocol for a single center, open label, randomised controlled trial, using a two arm design to determine whether exposure guided dosing (therapeutic drug monitoring – TDM) of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure compared to fixed drug dosing in participants with LN.

**Key Messages:**

- This study will determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants in achieving established targets of MPA exposure compared to the standard fixed dosing in participants with biopsy proven LN.
- This study will also determine whether there is a difference in the complete and partial remission rates between participants on fixed drug dosing and exposure controlled dosing of MPS in LN in induction group and renal relapse in the maintenance group.
- This study will try to validate a limited blood sampling protocol to measure exposure to MPA using a 0-12 hour, 17 sample- based area under curve (AUC)

**Strengths and limitations:**

- This prospective randomised study is designed specifically to test whether exposure controlled dosing results in a higher proportion of participants achieves target exposure levels of MPA compared with exposure controlled dosing.
• Size of the sample studied will limit the power of observations.

Background

Mycophenolate mofetil (MMF), the first prodrug of mycophenolic acid (MPA), has been used in kidney transplant recipients for the prevention of acute rejection in combination with steroids and calcineurin inhibitors since 1995 in the USA and 1996 in Europe (1). A second MPA product, the enteric coated mycophenolate sodium (EC-MPS) became available subsequently. Clinical trials have shown that EC-MPS is therapeutically equivalent to MMF with comparable safety profiles and equimolar doses of the two drugs producing equivalent MPA exposures (2, 3). The favourable experience with MMF in transplant recipients resulted in it being used in trials involving participants with autoimmune and other immunologically mediated renal diseases (4, 5, 6, 7, 8). The Aspreva Lupus Management Study group (ALMS) found rates of adverse events, particularly infection, between MMF and intravenous cyclophosphamide to be similar in lupus nephritis (LN) (9). Furthermore, a recent meta-analysis of randomised controlled trials showed that MMF was superior in inducing remission in severe LN and had fewer side effects compared with pulsed cyclophosphamide (10). Other clinical trials reported similar results with EC-MPS (11, 12, 13, 14). The Therapeutic Goods Administration of Australia has approved EC-MPS-Myfortic® (www.novartis.com.au/DownloadFile.aspx?f=myf.pdf) for the treatment of classes III, IV, V and V LN (15).

Dosing and therapeutic drug monitoring (TDM) of MMF/MPS

MMF is usually administered at a fixed dose of 1000 mg twice daily in transplant recipients (independent of weight) and modified according to clinical tolerance. The randomised controlled trial, the Adaption de Posologie du MMF en Greffe Renale (APOMYGRE), and the fixed dose versus concentration controlled (FDCC) studies investigated the benefit of using TDM but results were not consistent (16, 17). APOMYGRE showed a reduction in acute rejection whereas the FDCC study had a neutral effect. To date, there is currently no consensus on using TDM of MPA...
to optimise MMF use in transplant patients (18, 19, 20, 21).

The dose of MMF for induction and maintenance therapy in LN varies from 2 to 3 gm a day (22). In the ALMS study, the median MMF dose was 42-mg/kg body weight by 20-24 weeks and 91.3% of participants tolerated daily doses of 2.5 to 3 gm daily (23). In a study by Petruck et al, 720 mg of MPS and 1000mg of MMF were found to deliver near equimolar exposures of MPA (24).

Inter-individual variability of MPA

Factors affecting the inter-patient variability of MPA have been extensively investigated in transplant recipients and are likely to be similar in LN (25, 26). The clearance of MPA depends on its non-protein bound fraction (26). Therefore, patients with reduced renal function and hypoalbuminemia have higher free fractions of MPA, theoretically resulting in higher MPA clearance and a lower MPA exposure. Furthermore, co-therapy with calcineurin inhibitors, phosphate binders, steroids and rifampicin may affect MPA pharmacokinetics (26). Nonetheless, the MPA concentration–effect relationship is more likely to be linear in LN patients treated with MMF and steroids, as opposed to transplant recipients who are treated with many immunosuppressive agents (27).

TDM of MPA in LN

Neumann et al. reported on the value of measuring MPA plasma concentrations in patients with autoimmune diseases (28, 29). In their study, there was a weak correlation between the 12-hour trough (C0) MPA concentrations and the area under the curve (AUC), with remission being associated with higher MPA trough concentrations (> 3.5 mg/L). There was a clustering of adverse events in participants with a high MPA exposure, thus refining the therapeutic window. In contrast, studies in renal transplant participants showed tolerability correlated poorly with MPA
concentrations. Neumann et al proposed in their exploratory study that MPA trough levels between 3.5 and 4.5 mg/L be used for maintenance of remission and prevention of adverse events. Roland et al, in a prospective pharmacokinetic study of MMF in patients treated for systemic lupus erythematosus, found a high inter-individual variability of MPA AUC levels (30). The therapeutic range of MPA has to be better defined with the clinical response to exposure controlled dosing in patients with LN.

**Limited Sample strategy (LSS)**

Measurement of AUC 0-12 hours has been well documented in transplant literature and a target AUC 0-12 of 30mg/L/h to 60mg/L/h is advised to reduce the risk of rejection (31, 32). For treatment with MMF, LSS was suggested as an alternative because MPA AUC 0-12 was laborious and expensive (33, 34). LSS has been trialed for EC-MPS showing that time points from the initial half of the full concentration time profile produced near identical results (35). Neuman et al found that MPA exposure expressed as MPA AUC\textsubscript{0-12} was comparable in patients with autoimmune diseases and renal transplant patients treated with EC-MPS (36). They suggested an LSS for estimating MPA exposure could be valid in autoimmune disorders. A more recent study using MPS by Fructuso et al suggested an AUC over 8 hours could be calculated with four blood samples, correlating favourably with an AUC\textsubscript{0-12} (37).

Our study will include participants who have blood sampled over a period of 8 hours or 12 hours. For the 8-hour sampling period, the AUC\textsubscript{0-12} will be calculated imputing the pre-dose sample value for the 12-hour sample value. With few studies in LN treated with MPS formulations measuring the relationship of MPA levels to efficacy and toxicity, this prospective randomised controlled trial will add more information on the pharmacokinetics and pharmacodynamics of MPA in LN (38, 39).

**Aim**
This study is to determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving targets of MPA exposure in LN compared to fixed drug dosing.

**Methods/Design**

**Study design and setting**

The study is a prospective, open-label, randomised controlled trial.

Participant population: Participants will be selected from either inpatients at Royal Brisbane and Women’s Hospital (RBWH) Renal and Rheumatology Departments or patients attending the Renal Rheumatology Lupus Vasculitis Clinic. This study will be done in collaboration with the Burns, Trauma and Critical Care Research Centre, School of Medicine, The University of Queensland and Department of Chemical Pathology, Pathology Queensland, Queensland Health.

The interventions will comprise of two groups:

*Intervention – Control*

Group 1: Fixed Dose Regime: oral EC-MPS 30mg/kg body weight to induce remission. MPS dosage will be reduced by 180 mg twice daily on achieving complete remission or if there are side effects such as diarrhea or leucopenia (total white cell count <3500/mm³ or opportunistic infections).

*Intervention – Experimental*

Group 2: Exposure Controlled dose: oral EC-MPS dose will be titrated according to the AUC₀₋₁₂ adjusted to a target AUC₀₋₁₂ of 40 to 60 mg/L·h. The dosage will be reduced if the AUC₀₋₁₂ is above 60 mg/L·h and once there is complete remission, an AUC of 30 to 50 mg/L·h will be maintained. All participants in the control and intervention groups will undergo pharmacokinetic analysis of MPA.
Other than EC-MPS dosing, both groups will be given similar management of LN including treatment with corticosteroids. Below is an illustration of the study design:

(Figure 1. POEMSLUN study design)

Identification of eligible participants
Participants with biopsy proven Class III/IV/V LN who fulfill the inclusion and exclusion criteria are eligible for the study. The inclusion criterion has been kept as broad as possible to represent the participant population and the exclusion criteria as restricted as possible to maximise validity and generalisability of findings.

Inclusion criteria
All participants 18 years of age and above with Class III/IV/V LN proven by renal biopsy and have been on EC-MPS for more than two weeks either as maintenance or induction therapy will be eligible for this study.

Exclusion criteria
Participants will be excluded if there is a history of psychological illness, a condition which interferes with their ability to understand or comply with the requirements of the study or who are unable to give consent. Pregnant, nursing (lactating) women and women planning on getting pregnant during the study period and not using contraception will be excluded. Finally, those with a history of malignancy treated or untreated within the past 5 years (with the exception of localized basal or squamous cell carcinomas of the skin) regardless of local recurrence or metastases will also be excluded from the study.

Informed Consent:
At the recommendation of the treating clinician who will seek permission from the participant or authorised surrogate to be approached by the investigator, the investigator/s will seek informed consent or assent from potential trial participants or authorised surrogate. This will occur through a verbal presentation of the written consent document, which the participant or authorised surrogate would then be given sufficient time to consider before consenting to the study or not.

Participants
Participants are randomised in permuted block sizes of 2 and 4 with the percent 33 and 66 respectively and stratified for induction and maintenance therapy with EC-MPS. Masking of investigators and participants will not be possible. Nonetheless, the laboratory staff analysing the pharmacokinetics of MPS will be masked to the treatment allocation. An individual’s participation in the study will cease at the end of the study period, which will be 12 months after the last participant is recruited. The recruitment period is 36 months. It is anticipated that the average follow-up time will be 24 months, assuming a steady recruitment rate of 12 participants per year.

The participants will have regular clinic appointments and follow up to improve adherence. A trial pharmacist will be involved with the study and will detail the changes in medication doses and monitor participant adherence.

Adverse Events:
Adverse events are defined as any untoward medical event (clinical or laboratory) experienced by a participant during the course of this clinical trial and considered by the investigator to be related to the study. All adverse events will be recorded on the Adverse Event page of the case report form and reported immediately to the Human Research and Ethics Committee (HREC) in writing.

Adverse events will be reported from the day of consent. The responsible investigator will determine whether the degree of any untoward event warrants removal of any participant from the
study. He/she will institute appropriate diagnostic and therapeutic measures and keep the participant under observation for as long as is medically indicated.

Outcome measures

Primary

This is a study to determine whether TDM guided dosing of EC-MPS results in a higher proportion of participants achieving established targets of MPA exposure compared to the standard empirical dosing in participants with biopsy proven LN.

Secondary

This study will also determine whether there is a difference in the complete and partial remission rates between participants on fixed drug dosing and exposure controlled dosing of MPS in LN in induction group and renal relapse in the maintenance group.

Complete remission is defined as a decrease in urinary protein measured over 24 hours to less than 0.53 g/24 h, a urine protein/creatinine ratio (uPCR) of less than 0.35 mg/mg (520 mmol/mg) with a normal urinary sediment, normal serum albumin and stabilisation (+ 25%) or improvement in serum creatinine levels at week 24 from the first sample. Partial remission is defined as stabilisation (+ 25%) or improved renal function (but still not to normal with reduction of proteinuria by more than 50% ranging between 0.3 to 3g/24h and a serum albumin of more than 30g/L (40). Renal relapse is defined as “recrudescence of renal disease after an initial response demonstrated by a recent increase in serum creatinine by >50% with active urinary sediment and or increase in proteinuria to 3.5 g/day or greater” (41). Proteinuria will be measured using the urine protein to creatinine ratio or by measuring the 24-hour urinary protein excretion. The urine protein to creatinine ratio is numerically equal to 24-hour urinary protein excretion in grams.

Secondary outcome measures include the time required to achieve complete or partial remission,
the assessment of improvement with the SLE Disease Activity Index (SLEDAI) score as well as C3, C4 and anti-dsDNA levels, the development of a pharmacokinetic model that can be used to develop MPS dosing recommendations in LN participants treated with MPS, validating the LSS for determining $AUC_{0-12}$, and the evaluation of the cost effectiveness of TDM analysis of MPS. An individual who is masked to the study allocation and not involved in the clinical care of the participant will adjudicate outcome measures.

Data Collection

Clinical and demographic data are collected for each participant, including age, gender, weight, height, allergies, clinical information, other co-morbidities, concomitantly prescribed drugs, serious adverse events, safety and treatment outcomes (clinical and/or immunological improvement) including SLEDAI scores. (Table I)

Laboratory investigations are performed consisting of renal function assessments, urine sediment examination, 24 hour urinary protein and creatinine measurement, eGFR (Modification of Diet in Renal Disease: $GFR(\text{mL/min/1.73 m2}) = 175 \times (\text{S. Cr})^{-1.154} \times (\text{Age})^{-0.203} \times (0.742 \text{ if female}) \times (1.212 \text{ if African American})$ (conventional units) (42)), liver function tests, complement components C3 and C4, antinuclear antibody (ANA), anti-double stranded DNA and pharmacokinetic analysis of mycophenolic acid (MPA).

The above information will be collected every 12 weeks and the presence of any serious adverse effects will be continually monitored and recorded during the study period. It is anticipated that the average follow-up time will be 18 months assuming a constant recruitment rate.

Data analysis

Blood samples will be collected by a dedicated research nurse at 15 time points for the 8 hour
group and 17 samples for the 12 hour group, including the time points from previously described LSS data for mycophenolate sodium at 0, 1.5, 4 and 8 hours post-dose, on three different occasions. Blood samples for the 8-hour group will be collected at half hourly intervals initially until 7 hours and the last sample at the 8th hour. Blood samples for the 12-hour group will be collected as for the 8-hour group along with further samples at the 10th and 12th hour. Samples will be kept on ice until centrifugation (3000 rpm for 10-minutes) and will then be analysed by High Performance Liquid Chromatography at Pathology Queensland (Royal Brisbane and Women's Hospital, Herston, Australia).

Statistical methods

A sample size of 32 participants is projected with 16 in each group. The sample required to test the ability for TDM guided dosing to achieve target MPS exposure compared with no TDM, is based on pharmacokinetic data from patients with lupus nephritis by Lertdumrongluk et al (43). Using a 95% confidence interval, predicting that 50% of patients will have exposures under the target range requires a total sample of 30 participants. We will collect data from 32 assuming there is less than a 10% attrition rate (44).

Comparisons between groups for the outcome variable for complete and partial remission will be performed using Chi Square or Fisher’s exact tests followed by a multivariable logistic regression analysis of concentrations from 4-8 hours. Vz = CL/λz, apparent elimination half-life = ln (2)/λz.
analysis to estimate the association between outcome and the groups. The secondary outcome of interest, namely, time to complete/partial remission will be evaluated using Kaplan-Meier survival curves, log-rank test. Multivariable Cox regression models will be used to estimate the effect of group adjusting for other covariates. Student T-test or Mann-Whitney U test are used to compare the continuous variables. Differences in infection rates (number of infections/total follow-up time) and serious adverse events between the 2 groups will be analysed by Z tests. All data will be analysed on an intention-to-treat basis, and a significance level of 0.05 will be assumed.

**Ethical considerations and dissemination**

The Human Research and Ethics Committee of the RBWH have approved this study. The investigators will comply with and conduct the study in accordance with Good Clinical Practice Guidelines, the principles that have their origins in the “Declaration of Helsinki” adopted by the World Medical Association in October 1996, the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research (2007) or replacement, and or other relevant NHMRC publication or guideline that relate or may relate to clinical trials (45).

Withdrawal of study medication may be made at the discretion of the treating physician or investigator following a serious adverse event. However, participants will continue to be followed for the duration of the study if possible, even if they have stopped treatment. This will include attendance at scheduled trial visits, and data collection, particularly of outcomes. The investigator may withdraw a participant from study medication at any time if it is felt to be in the best interests of the participant, where there is disease progression or non-adherence to study medication.

Under such circumstances, participants will continue to be monitored for outcome events and will attend scheduled trial visits so that results can be analysed on an intention to treat basis. If a participant withdraws consent for the study they shall be withdrawn from the study. Any participant is free to withdraw their consent at any time without the need to justify their decision.
We plan to publish the results in medical journals and present the de-identified information at conferences.

**Protection of participant confidentiality**

Participants' records and the data generated by the study will be confidential in line with the recommendations of the Australian NHMRC and locally applicable laws. Standardized case report forms will be provided for each participant on this study. The participants in this study will be identified only by initials and subject number on these forms. Any information that may identify a participant will be excluded from data presented in the public arena. Data will only be shared among the investigators. Individual participant's medical information may be given to the treating clinician where deemed clinically necessary. De-identified information will not be released. Data collected as part of this trial will be stored on a computer data base held by the principal investigator in a secure, lockable location. The data will be stored for 15 years after completion of the project in accordance with the revision of the Joint NHMRC/ Australian Vice Chancellors' Committee (AVCC) statement and guidelines on research practice (45).

**Discussion**

Several studies have demonstrated that MMF/MPS is effective at gaining control of severe LN. The variations in pharmacokinetics of MPA/MPS and the factors causing these differences have been studied in transplant recipients but are not well documented in those with LN. The primary objective of this study is to examine whether exposure controlled MPS dosing results in higher proportion of participants achieving targets of MPA exposure compared to standard empiric dosing in participants with LN. Secondary objectives include the efficacy of exposure controlled MPS dosing in LN with TDM, the relationship between the disease activity of LN and MPA blood concentrations (pharmacodynamics), and using the data to develop dosing recommendations.
for MPS in LN. Defining the optimal therapeutic range for MPA is likely to help improve outcomes in participants with LN treated with MPS. The consequences of failure of immunosuppression in LN can be severe and can lead to end stage renal failure. By personalising MPS dosing for participants with LN using TDM, it may be possible to maximise therapeutic efficacy while preventing significant complications, therapeutic failure and toxicity.

Current status of the study

The study has commenced and is in its early stages. The recruitment rate will be assessed periodically and if the target is unlikely to be met, we will invite other nephrology centers in Queensland to participate in the study.

Author contributions

DR, GJ and JR designed the study and wrote the protocol. DR is the Principal investigator and JR and GJ are equal senior authors. HH, JL and RGF provided advice reviewed the study protocol and ethics application. PK provided input and will be involved with the recruitment component of the study. JR, JU and BMcW will be involved in the analysis of samples. AL, MLP, MR, and RR will be involved in the collection of blood samples and data collection. AL assisted in preparing the manuscript. All authors read and approved the final manuscript.

Competing interests:

DR and GJ were principal investigators for Ascertain study sponsored by Novartis Australia (pte) limited and Novartis India (pte) limited respectively.
**Funding statement:**

This study is funded by a Research grant from the RBWH Research Foundation and an unrestricted grant Novartis Australia (Pte) limited. The study funders have no role in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication. The investigators will have ultimate authority over each of these activities.

**Acknowledgements**

We thank Drs. Sree Krishna Venthurupalli and Jennifer Martin, members of Data Safety monitoring board and Dr Shankar Viswanathan for advice on statistical methods.

**REFERENCES**


Figure 1. POEMSLUN study design
Table 1: Visit schedule

<table>
<thead>
<tr>
<th>Visit Schedule</th>
</tr>
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<tbody>
<tr>
<td>1. Randomisation – Stratification: Induction and Maintenance</td>
</tr>
<tr>
<td>2. Induction: MPS 30mg/kg B W</td>
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<tr>
<td>3. Fixed Dose</td>
</tr>
<tr>
<td>4. Monitor AUC</td>
</tr>
<tr>
<td>5. Remission in 6 months</td>
</tr>
<tr>
<td>6. YES</td>
</tr>
<tr>
<td>7. Reduce by 180mg b.d.</td>
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<tr>
<td>8. Maintenance Phase</td>
</tr>
<tr>
<td>9. Monitor AUC 3rd sample: 29-32 weeks</td>
</tr>
<tr>
<td>10. NO</td>
</tr>
<tr>
<td>11. YES</td>
</tr>
<tr>
<td>12. Maintenance Dose: Reduce dose by 180mg b.d. and adjust to AUC 32-50mgH/L</td>
</tr>
<tr>
<td>13. NO</td>
</tr>
<tr>
<td>14. Remission in 6 months</td>
</tr>
<tr>
<td>15. Drop Out</td>
</tr>
<tr>
<td>16. Treatment failure</td>
</tr>
<tr>
<td>17. Unachievable remission</td>
</tr>
<tr>
<td>18. Drug failure or intolerance</td>
</tr>
<tr>
<td>19. Requiring alternative agents</td>
</tr>
<tr>
<td>20. Non compliance</td>
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</table>

Pharmacokinetics of Mycophenolate Sodium (MPS) in Lupus Nephritis
<table>
<thead>
<tr>
<th>Test</th>
<th>Study Visit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 (Baseline)</td>
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<tr>
<td>Demographics</td>
<td>X</td>
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<tr>
<td>Medical history</td>
<td>X</td>
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<td>Clinical assessment</td>
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<td>SLEDAI assessment</td>
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<td>Renal Function Assessment</td>
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<td>Immunological Study</td>
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<td>Adverse event assessment</td>
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<tr>
<td>Pharmacokinetic analysis -Total 3 sampling occasions* –</td>
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</table>

**List of abbreviations**

POEMSLUN - Pharmacokinetics of Enteric Coated Mycophenolate Sodium in Lupus Nephritis

EC-MPS- Enteric coated Mycophenolate sodium

MMF- Mycophenolate mofetil

LN - lupus nephritis
MPA - mycophenolic acid
TDM - therapeutic drug monitoring
LSS - limited sampling strategy
SLE - systemic lupus erythematosus
S. Cr - Serum creatinine
uPCR - urine protein/creatinine ratio
SLEDAI - SLE Disease Activity Index
NHMRC - National Health and Medical Research Council
Pharmacokinetics of Mycophenolate Sodium in Lupus Nephritis

Randomisation – Stratification:
Induction and Maintenance

Induction: MPA 30mg/kg B W

Fixed Dose

Monitor AUC
1 sample: 1-2 months
2 sample: 3-4 months

AUC driven dose
40-60 mgH/L

Remission in 6 months
NO

YES

Drop Out
- Treatment failure
- Unsatisfactory remission
- Drug failure or intolerance requiring alternative agents
- Non compliance

YES

Reduce by 180mg b.d.

Maintenance Dose:
Reduce dose by 180mg b.d. and adjust to AUC 30-50mgH/L

Remission in 6 months

NO

YES

Reduce by 180mg b.d.

Maintenance Phase
Monitor AUC 3rd sample: 7-8 months

Pharmacokinetics of Mycophenolate Sodium in Lupus Nephritis
101x90mm (300 x 300 DPI)
Table 1: Visit schedule

<table>
<thead>
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<td>3 (12th week)</td>
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<td>4 (14-16 weeks)</td>
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<td>7 (28-32 weeks)</td>
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<td>8 (36th week)</td>
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<td></td>
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<td>X</td>
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<td>Medical history</td>
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<td>LEDAI assessment</td>
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