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Please note: this presentation, including questions from the audience, is being recorded

DILIsym Review Session 25:

SimPops Design and Construction

August 30, 2018

Diane Longo

DILIsym Review Session Agenda

- Brief introduction to SimPops
- Processes for constructing SimPops
- SimPops included in DILIsym
- Examples of SimPops applications
- Future developments in SimPops generation

Population Variability is Important for the Prediction of Low-Frequency Events Such as Drug-Induced Liver Injury (DILI)

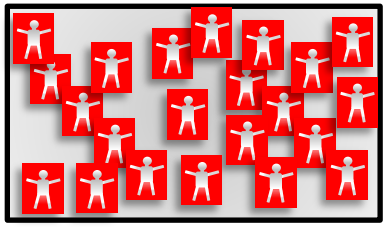
- Most drugs with DILI liabilities do not cause DILI for every individual
  - Would not be predicted by simulations of an “average” or “median” human or animal
- Including variability in individual characteristics that lead to DILI susceptibility is crucial
  - Can also isolate potential individual risk factors

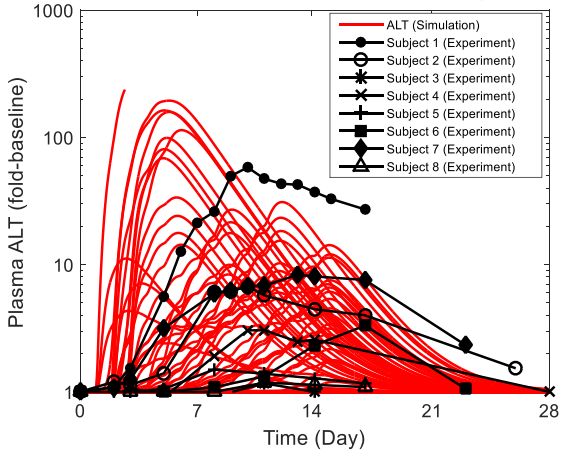
Drug	Clinical ALT Elevation Frequency
Troglitazone	2%
Bosentan	8-18%
Tolcapone	3%
APAP (Therapeutic Dose)	31-44%

Range of Hepatotoxic Responses in SimPops Due to Variability in Underlying Biochemistry

- SimPops are population samples with variability in hepatotoxic drug responses
- Multiple parameters are varied to produce diverse simulated patients
- Numerous simulated patients are generated, consistent with range of observed response data and known parameter distributions
- SimPops compared with reported clinical data where available
- SimPops are subsequently used to predict responses to novel compounds

Example of Variables Used to Construct SimPops
Body weight
Glutathione levels and synthesis
RNS-ROS clearance
Mitochondria function
Bile acid transporter function
Adaptive responses to bile acid levels
Apoptotic sensitivity to RNS-ROS
Necrotic sensitivity to ATP reductions
Hepatocyte regeneration

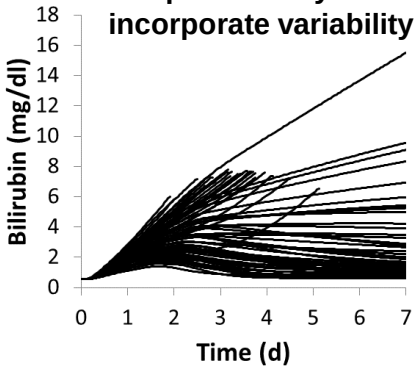




Clinical Data and Simulation Results

Treat SimPops with Compound X

Novel predictions of hepatotoxicity that incorporate variability



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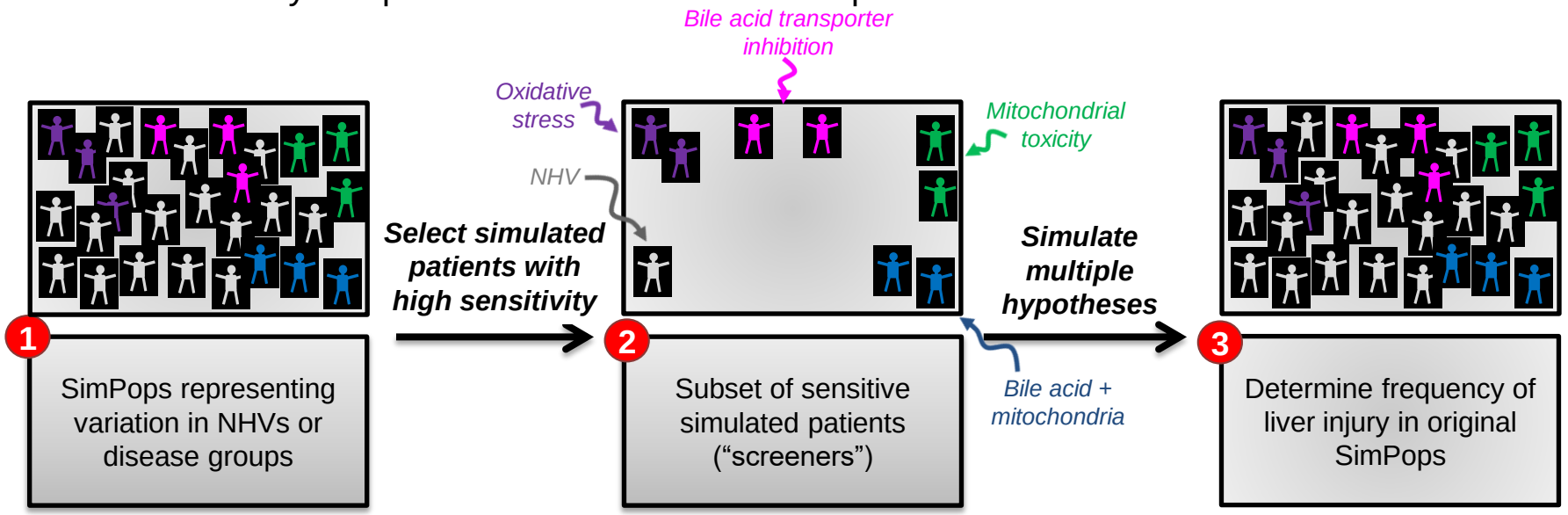
Generation and Use of Subsets of Simulated Humans (SimCohorts) in DILIsym

- SimCohorts consisting of a subset of individuals from existing SimPops are used for screening and preliminary simulations and are adequate for many analyses
  - Computationally less-expensive for testing multiple hypotheses prior to full SimPops
  - ***Provided with DILIsym for many of the SimPops – DILIsym documentation explains purpose of each***
- Multiple approaches for selecting individuals from larger SimPops
  - Select simulated individuals with high sensitivity
  - Select individuals based on parameter values (i.e. body weight)
  - Randomly sample individuals from full SimPops



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DILIsym Review Session Agenda

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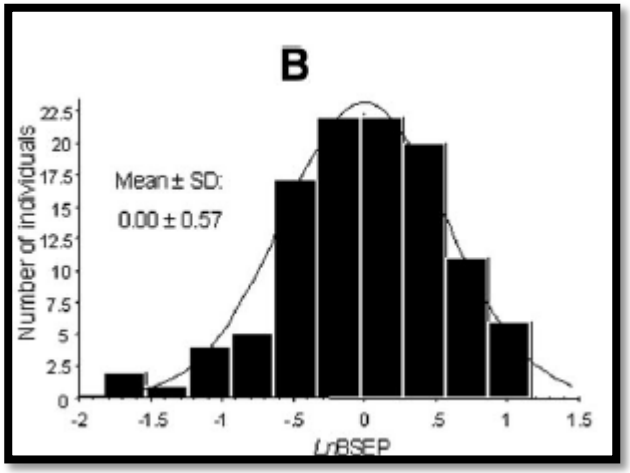
The Scope of a SimPops Was Determined As a First Step

Select Key Features of the SimPops

1. Species
2. DILI mechanisms to include
3. Population characteristics
   - Healthy volunteers or disease patients?
   - Any demographic focus (i.e. ethnicity, age subgroup, etc.)?
4. Size of the SimPops
   - Target size is usually ~200-300 individuals
   - Tradeoff between including high number of individuals and computation time to run the SimPops
5. Define endpoints for successful sample population generation
   - Identify available outcome data

Understanding Available Data Necessary for Constructing the SimPops

- Creation of a SimPops requires an understanding of *which characteristics are likely to be variable among a population and how those relate to parameters and groups of parameters in DILIsym*
  - e.g., protein expression is likely to vary while protein affinity for substrate is not; this means a transporter V_{max} should be in a SimPops while a transporter K_m should not
  - Some parameters can represent the variability in a larger system



Meier *Hepatology* 2006

	Before fenofibrate			
Bile acid	Mean	SEM	10th[a]	90th[a]
CDCA	256.9	29.5	16.4	610.9
TCDCA	92.9	8.8	12.7	268.5
GCDCA	745.9	54.2	169.8	1,694.2
CA	176.2	27.1	2.6	403.2
TCA	113.7	15.8	8.1	269.5
GCA	198.4	16.9	29.8	461.5
UDCA	106.2	7.9	13.6	269.1
TUDCA	6.1	1.2	0.00	13.3
LCA	17.6	1.3	4.4	34.3
TLCA	19.1	1.1	BLQ	32.3
GLCA	18.4	1.7	4.6	35.0
LCA-S	7.0	0.6	BLQ	14.4
DCA	393.1	24.6	102.9	782.4
TDCA	35.1	3.2	4.5	81.6

Trottier *Clin Pharm Ther* 2011

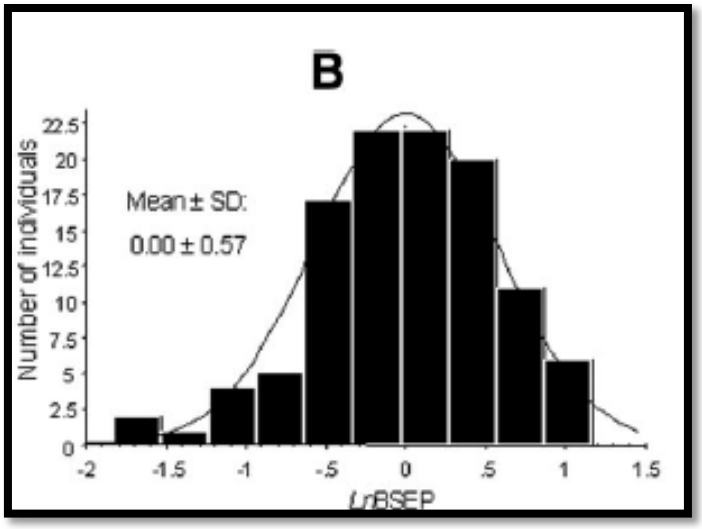
- In order to construct a SimPops, two kinds of data can be used
  - Data representing the range of the variable parameter
  - Data representing the potential range of outcomes for a population (toxicity, bile acid profiles, etc.)

Parameters to Vary in the SimPops Selected Based on Literature Review

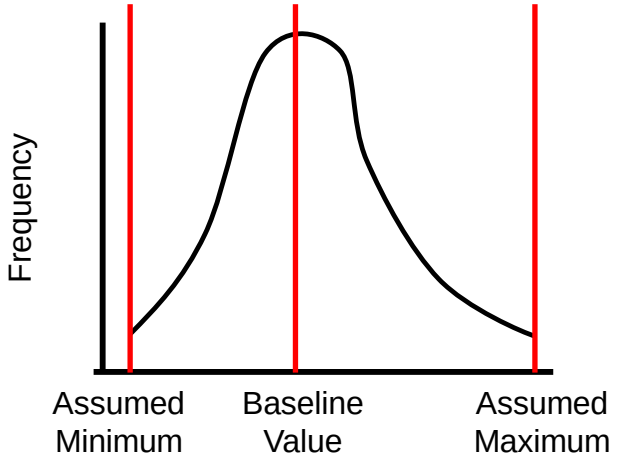
- Determine parameters to be varied based on the scope of the SimPops and available data
  - If the size of your SimPops is limited by computational power, you will need to compromise on the number of parameters included
    - Focus on the primary purpose of the SimPops
  - Gather available information on the distribution for each parameter
    - Parameter distributions defined based on reported ranges or distributions when available
    - Parameter distributions assumed when no reported information on the variation is available
      - Use reasonable assumptions for CV or standard deviation
- To make predictions with parameter values that are extremely unlikely (at the far tails of the distribution), weighting of simulated patients and very precise data may be needed
  - **This is different than predicting an unlikely event based on a combination of parameter values**

Methods Used for Determining Parameter Distributions for SimPops

- Published or internal data can be used to determine range and distribution of parameters
  - Example: BSEP protein assay can be used to determine likely distribution for canalicular V_{max} parameters
  - Care should be taken when extrapolating mRNA/gene data; DILIsym parameters depend on protein activity, which may or may not correlate
- If no data exist, parameter ranges can be assumed
  - Can choose a maximum and minimum value based on the baseline parameter value in DILIsym
  - Can choose a standard deviation based on desired amount of variability
  - 50% +/- as max/min representing 2.5 SDs from the mean tends to be a good starting point (SD of 20% assumed)
  - ***All the distributions for DILIsym SimPops can be found in the SimPops documentation, including parameters where distribution was assumed***



Meier *Hepatology* 2006



Clinical Data

Basic Methods Used for Creating SimPops

1. Genetic algorithm method
   - Focuses parameter distribution on known outcomes (e.g. ALT elevation distribution, PK profile, BA plasma concentrations)
2. Known distribution method
   - Focuses on creating individuals based on adherence to a known population distribution of the parameters
3. Combination of both methods
   - Includes generation of initial, starting simulated population with known distribution bias, followed by the genetic algorithm fitness function
   - Allows parameters to adhere to defined distributions (to some degree) while also ensuring outcomes are reasonable for simulated individuals
4. Method depends on data available and confidence in those data

Generating SimPops by Sampling from Distribution for Each Parameter

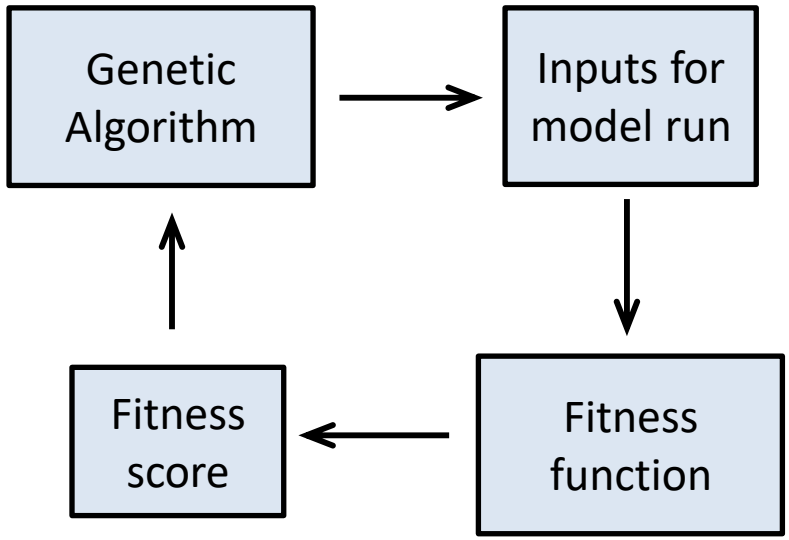
- Create individuals based on adherence to a known or assumed population distribution for each of the parameters
- Validate by comparing simulated outcomes with clinical data
- Curate, if necessary, by removing unlikely simulated individuals
- Example:
  - Assume creating a SimPops of n=300 individuals with variation in 5 parameters relevant to a key DILI mechanism

Parameter 1	Data available describing distribution
Parameter 2	Data available describing distribution
Parameter 3	Data available describing distribution
Parameter 4	No data available on distribution, assume parameter distribution
Parameter 5	No data available on distribution, assume parameter distribution

  - Generate n=300 individuals for each parameter by sampling from the known or assumed distribution for each parameter
  - Validate with outcome data, curate if necessary

Generating SimPops with Genetic Algorithm Method

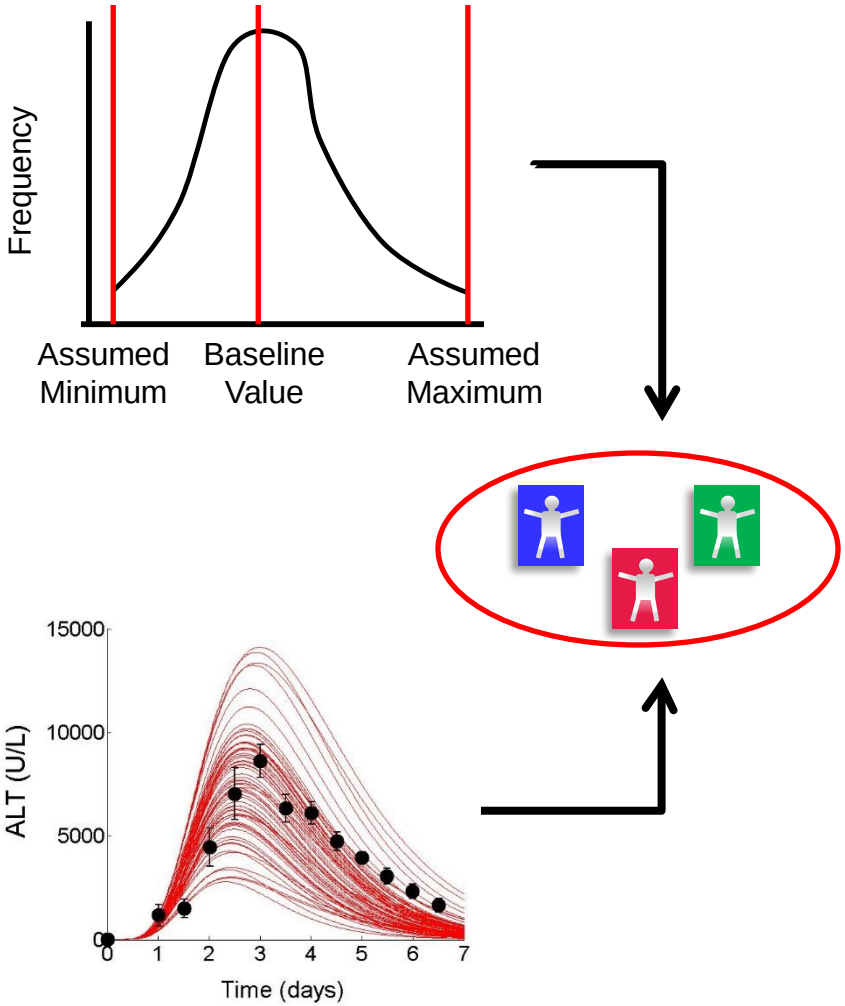
- Genetic algorithm loops through the following components:
  - Initial population generation (GA)
  - Fitness score generation (fitness function)
  - Next generation production (GA)



- Fitness function compares model inputs and model outputs with data
- Focus parameter distribution on known outcomes (ex. serum bile acid profiles)
- May be limited by computation time required
- May lead to odd parameter distributions

Combining Outcomes Data with Parameter Distribution Information for Selection

- The likelihood of occurrence of a particular simulated individual may be as important as their simulated outcomes
- Incorporate both data and distribution into a fitness function
  - Score for data can be produced by least-squares calculation
  - Score for probability can be produced by product of z-scores for each parameter
  - Sum of these scores would be overall fitness score



Clinical Data and Simulation Results

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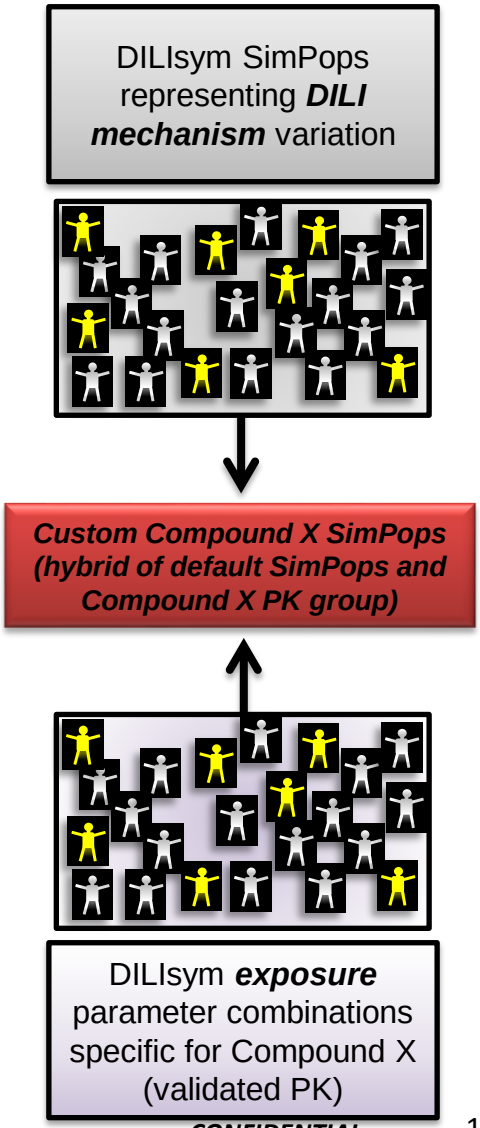
Customized SimPops Can Be Constructed to Recapitulate Compound X PK Variability

- Variability in parameters specific to exposure of a given compound can be superimposed on the existing SimPops
- Data used to optimize and validate the Compound X PK SimPops
- Parameter sets combined to create new SimPops
- PBPK parameters and associated distributions must be picked for each compound, if using DILIsym for this
  - GastroPlus PBPK outputs can also be exported and then imported into DILIsym using Specified Data to accomplish same goal more quickly
  - GastroPlus includes several special populations with respect to PK variability



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Approach Used to Generate Compound-Specific SimPops with PK Variability

- Existing SimPops in DILIsym used as a starting point
- Variability in parameters specific to compound of interest superimposed upon the existing SimPops
- Example:
  - Add PK variability for compound of interest to n= 285 Human v4A_1 SimPops
  - Select parameters to reflect clinical PK variability
    - For this example, assume variation in 3 PK parameters for compound of interest:
      - Compound X metabolism Vmax
      - Compound X renal clearance
      - Compound X biliary clearance
  - Generate n=285 individuals for the 3 PK parameters
    - Distributions based on data where available (i.e. reported variation in activity of relevant metabolic enzymes, etc.)
    - Confirm that variation in PK parameters recapitulates the range of exposure for the drug of interest
  - Combine the 3 PK parameters with the 34 v4A_1 parameters to generate the 37 parameter, n=285 compound-specific SimPops

Human v4A_1 SimPops:
34 parameters, 285 individuals

Compound PK variability:
3 parameters, 285 individuals

Compound-specific SimPops:
37 parameters, 285 individuals

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Select SimPops Included in DILIsym version 7A

SimPops	Abbreviated Reference Number	Species and Type	Important Notes
Human_ROS_apop_mito_BA_v4A_1	v4A_1	Human, healthy volunteers	
Human_T2D_ROS_apop_mito_BA_v6A_2	v6A_2	Human, Type 2 Diabetics	Includes disease-related variability in body mass, plasma glucose, plasma FFA, liver GSH, mitochondria function, lipogenesis, and lipotoxicity
Human_NAFLD_ROS_apop_mito_BA_v5A_1	v5A_1	Human, NAFLD (non-alcoholic fatty liver disease)	Includes disease-related variability in body mass, plasma glucose, plasma FFA, liver GSH, mitochondria function, lipogenesis, liver TG synthesis, plasma TG, liver bile acid uptake transporters, and lipotoxicity
Human_ROS_apop_mito_BA_ALT_v7A_1	v7A_1	Human, healthy volunteers	Combines DILI mechanisms with biomarker (ALT) parameters
Human_ROS_apop_mito_BA_Biogenesis_v7A_2	v7A_2	Human, healthy volunteers	Includes mitochondrial biogenesis (adaptation) parameters added to the v4A_1 SimPops
Dog_ROS_apop_mito_v3B_3	v3B_3	Dog, healthy	Beagle
Mouse_ROS_apop_mito_v3B_4	v3B_4	Mouse, healthy	Data from various strains used but most like C57Bl6
Rat_ROS_apop_mito_BA_v4A_2	v4A_2	Rat, healthy	Data from various strains used, but most like Sprague Dawley

All SimPops and SimCohorts are described at www.DILIsymHelp.com and within the Help Menu of the SimPops Feature

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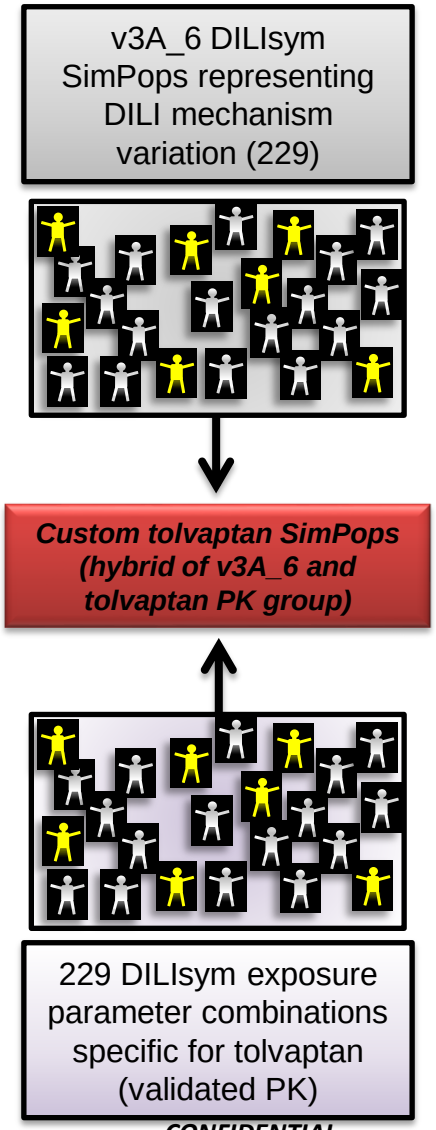
Customized SimPops Constructed to Recapitulate Tolvaptan PK Variability

- Variability in parameters specific to tolvaptan exposure superimposed on the existing Human_mito_BA_v3A_6 SimPops (N=229)
  - Existing SimPops includes variability in mitochondrial function, and bile acid transport
  - 229 tolvaptan ADME parameter combinations assigned randomly to existing individuals in v3A_6 SimPops within DILIsym
- Tolvaptan SimPops created by varying metabolism, and clearance values (ADME)
- Tolvaptan exposure variability validated with observed clinical variability



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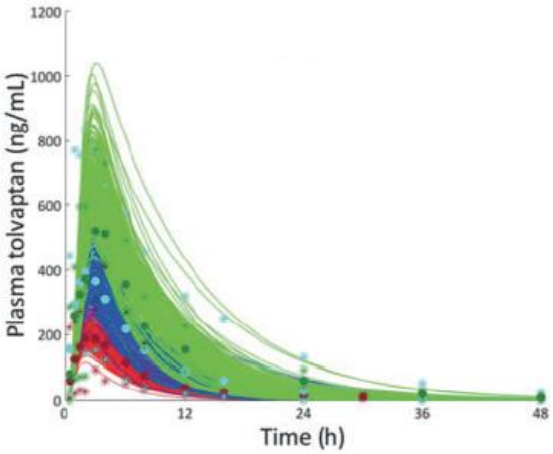
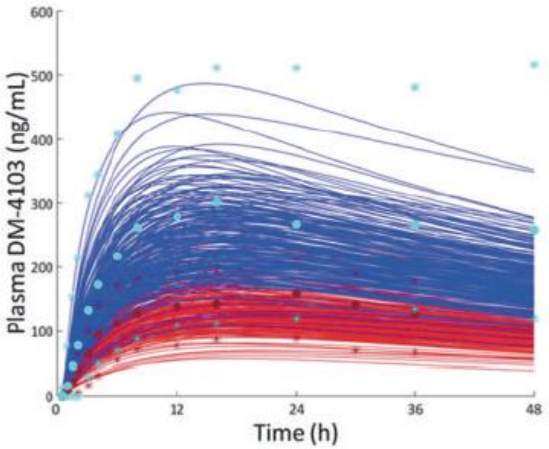
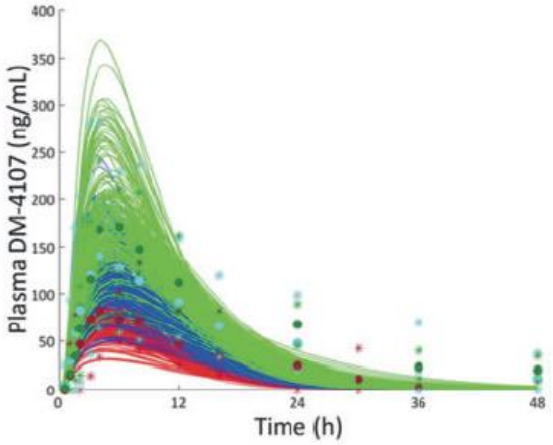
Customized SimPops Recapitulates Observed Variability in Plasma Concentration Range for Tolvaptan and Metabolites

- Simulated concentrations in customized SimPops recapitulate range of plasma concentrations in the clinical data for 30, 60, and 120 mg single dose studies for parent and metabolites







Woodhead 2016

Simulations of Tolvaptan in Customized SimPops Predict ALT Elevations Due to Multiple Hepatotoxicity Mechanisms

- Simulations with 90/30 mg daily, 180 days predicted ALT elevations in 18/299 (7.9%) of simulated individuals, comparable to incidence of ALT elevations (4.4%) in ADPKD clinical trials
  - Slight overestimate may be due to lack of inclusion of compensatory mechanisms
- Mechanistic investigation simulations suggest that both mitochondrial toxicity and BA toxicity contribute to observed toxicity
  - Both parent and DM-4103 metabolite suggested to contribute to liver injury

Simulation Conditions	Simulated Patients with ALT>3x ULN
Full toxicity§	18/229
No Tolvaptan toxicity	0/229
No DM-4103 toxicity	5/229
No Mito toxicity	9/229
No BA toxicity	0/229

§ In renally sufficient SimPops™ simulated with all molecular species and mechanisms, DILI was predicted in n=18/229 simulated patients. Simulations conducted without a particular mechanism or molecular species were used to investigate the contribution of each.

Woodhead 2016

Putative Tolvaptan Susceptibility Factors Identified with Covariate Analysis

- Covariate analysis performed to identify patient parameter values that predict tolvaptan-mediated DILI
- Four SimPops parameters significantly correlated with both ALT elevations and liver ATP reductions
  - Two parameters related to mitochondrial function
  - One parameter related to bile acid transport
  - One parameter related to drug distribution

SimPops Parameter	Max ALT *P*-value	Min ATP *P*-value
Basal ETC flux	.0001	<.0001
Respiratory reserve scaling factor	.0003	<.0001
CDCA-amide canalicular Vmax	<.0001	<.0001
Body mass	.0408	.0039

Woodhead 2016

Lixivaptan Project Example - Comparator

- Tolvaptan has been represented in DILIsym (*Woodhead 2016*)
  - DILIsym correctly predicted ALT elevations and Hy's Law cases at 120mg – simulated incidence was similar to clinical experience
  - Multifactorial toxicity: inhibition of bile acid transporters and mitochondrial respiration

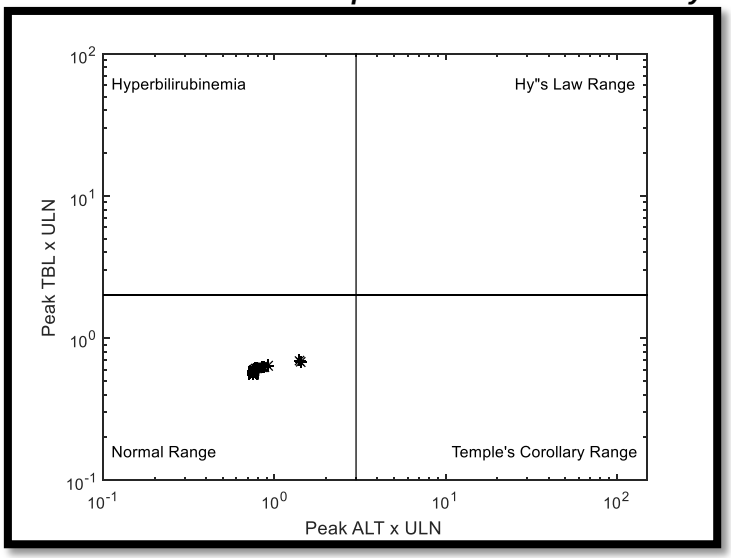
- Mechanistic representation of lixivaptan and its three major metabolites, WAY-141624, WAY-138758, and WAY-138451, developed in DILIsym to assess the potential liver toxicity risk of lixivaptan, especially in comparison to tolvaptan

Lixivaptan Project Executive Summary

- Simulations of lixivaptan dosing in custom SimPops of 285 simulated individuals with exposure variability showed no ALT elevations (0/285 >2X ULN) at 200/100 mg BID dosing

- The DILIsym results suggest that lixivaptan is likely safer than tolvaptan
  - Tolvaptan had significant ALT elevations at its clinical dose (simulated and clinically observed); lixivaptan simulations predict none

Simulated 200/100 mg dosing over 12 weeks in Custom SimPops of 285 with PK variability



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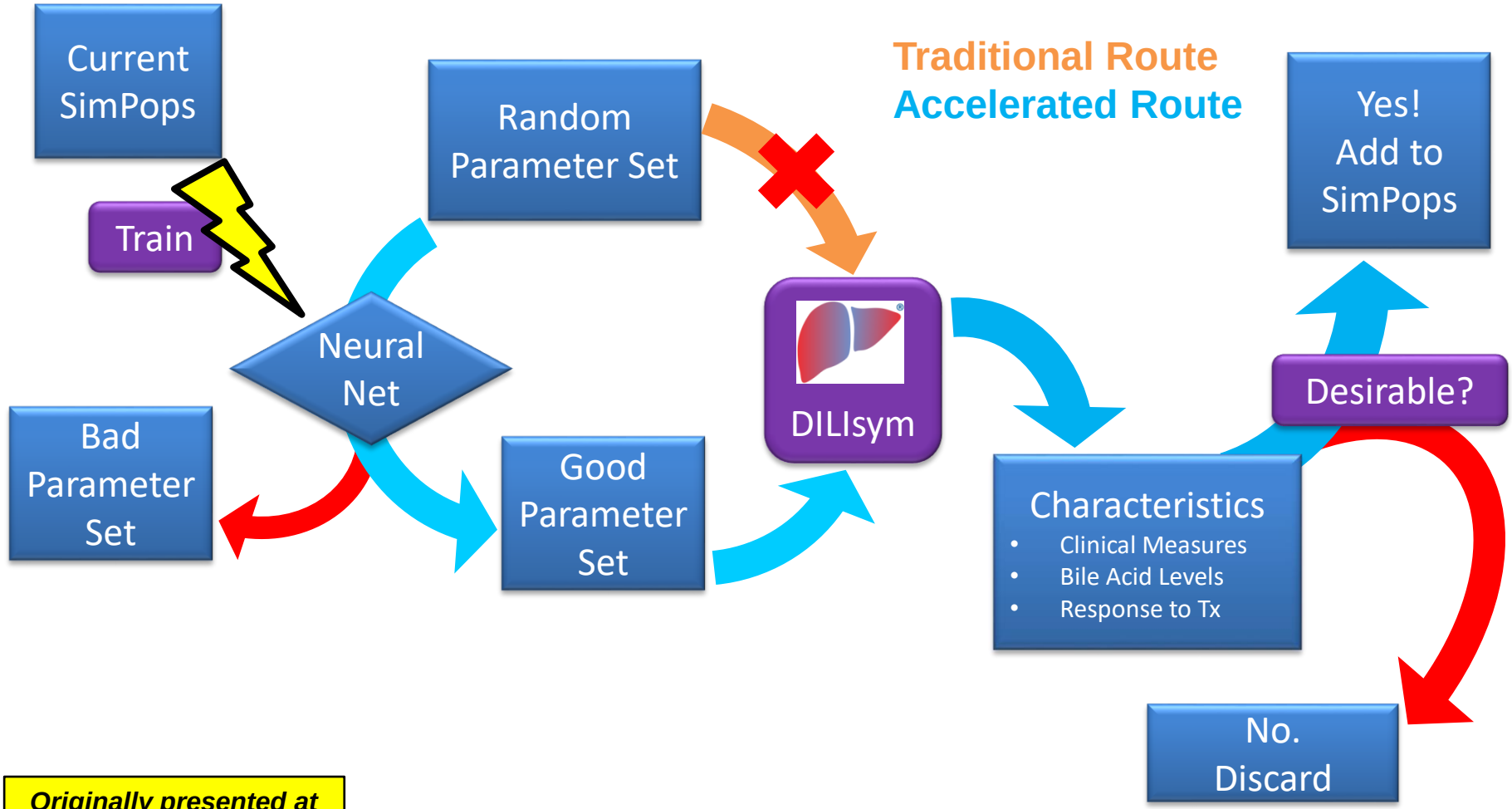
SimPops – Proposed Workflow to Accelerate SimPops Generation



Originally presented at Q2 2018 Update Meeting

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Summary

- DILIsym includes SimPops to account for interpatient variation
- Population variability is important for the prediction of low-frequency events such as DILI
- SimPops are used to explore how interpatient variability impacts susceptibility to DILI, to identify potential patient risk factors, and to assess the relative contribution of different hepatotoxicity mechanisms for a compound of interest

Upcoming DILIsym Review Sessions

Join us for:

- **Review Session 26: "Overview of the Hepatocyte Turnover Sub-model in DILIsym" October 4, 2018**