Paper DV03

Accelerating Study Insights: Agile Data Visualization Using R-Shiny

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ABSTRACT

Interactive, real-time data visualization is transforming how study teams assess efficacy and safety. This project leverages R Shiny to convert raw datasets into actionable insights with agility and precision.
The application converts raw efficacy data into structured analysis datasets and interactive visualizations, enabling study teams to explore efficacy trends rapidly and intuitively. Visualizations include Waterfall plots, Spider plots, Swimmer plots, Kaplan-Meier analyses, and Overall Response Rate tables, with listings also in spreadsheet format.
For safety, a dedicated Adverse Event (AE) module derives TEAE TFLs from raw datasets, enabling interactive exploration of safety profiles. Integrating safety with efficacy provides a holistic view of outcomes and balanced evaluation. By using this tool, study teams reduce reliance on static reporting and streamline transformation. An agile approach allows iterative refinement without waiting for SDTM/ADaM processing. This initiative positions statistical programmers as innovators in agile analytics, improves efficiency, and enables timely, data-driven decision-making.

INTRODUCTION

Oncology clinical trials generate complex, rapidly evolving datasets. Safety signals must be monitored continuously, while efficacy outcomes, including tumor burden changes and lesion-level dynamics—require iterative exploration by study teams. Traditional SAS-based SDTM/ADaM workflows often create a temporal lag, where waiting weeks for static TFLs delays access to critical insights.
To meet this challenge, we developed **VISTA** (**V**isualization **I**nterface for **S**tudy **T**racking & **A**nalytics). By leveraging R Shiny to generate validated visualizations directly from raw datasets, VISTA bypasses lengthy transformation cycles. This enables not only dynamic AE surveillance but also instant, full-spectrum efficacy visualization - transforming how teams track patient responses and accelerate decision-making.

OBJECTIVES

The primary objective of this paper is to introduce **VISTA**, an end-to-end analytics platform designed to accelerate decision-making in oncology trials. By bypassing traditional SDTM/ADaM transformation pipelines, VISTA enables the generation of real-time safety and efficacy TFLs directly from raw datasets. This paper demonstrates how VISTA integrates complex oncology visualizations—including Waterfall, Spider, and iRECIST-specific outputs—while maintaining strict alignment with Statistical Analysis Plan (SAP) definitions

METHODS

SYSTEM ARCHITECTURE

FUNCTIONAL LAYERS

The platform employs a modular Shiny architecture organized into distinct functional layers.

- **THE DATA LAYER** ingests raw datasets directly from source files, including demographics, randomization and registration, adverse events (AE), tumor measurements, treatment response, patient disposition, drug exposure, laboratory values, and biomarker data, etc.

- **THE DERIVATION LAYER** applies SAP-aligned transformations to produce analysis-ready variables using R, including treatment-emergent adverse event (TEAE) flags, response classifications, progression-free survival (PFS)/duration of response (DOR)/overall survival (OS) endpoints, percent change over time, and best change from baseline calculations.

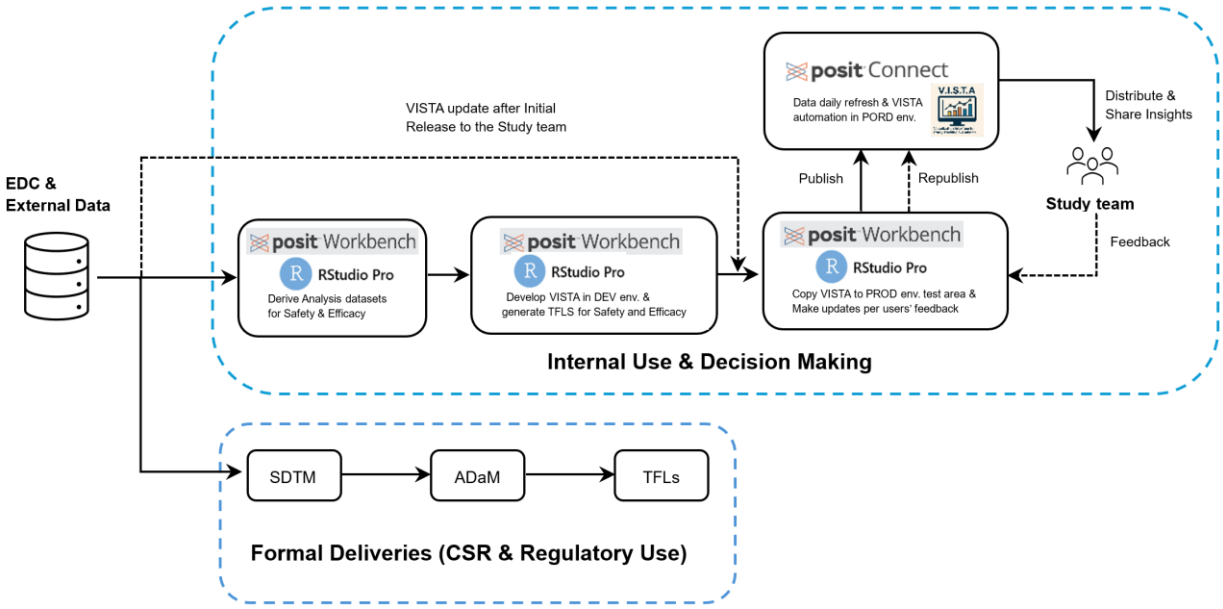
- **THE VISUALIZATION LAYER** generates interactive, real-time visualizations leveraging tidyverse, ggplot2, plotly, survival packages, and custom rendering functions (DT, gridExtra) to produce publication-quality plots, tables and listings.

- **THE FILTERING LAYER** provides dynamic, study-specific filtering options across tumor type, dose level, study phase, mono/combo cohort, SAP defined number of lines of prior systemic anti-cancer therapy and demographic subgroups, enabling users to subset data consistently across all outputs in real time.

- **THE EXPORT LAYER** supports multi-format downloads (PDF, PNG, XLSX) for offline review, presentation, and internal documentation.

DEPLOYMENT & CONFIGURATION

Deployment and configuration are managed through Posit Connect with role-based access controls to ensure appropriate data governance and security.



RAW DATASET TO ANALYSIS-READY DATASET

Raw clinical data are transformed into analysis-ready structures through a centralized derivation layer aligned with the Statistical Analysis Plan (SAP). This layer applies standardized logic to establish shared analytical foundations, including treatment exposure windows, population flags, assessment timing, and key analysis variables. Event and censoring rules, confirmation requirements, and longitudinal alignment are implemented consistently at this stage to ensure coherence across downstream analyses. By standardizing these transformations upfront, the framework supports efficient safety and efficacy analytics while maintaining consistency with regulatory-grade outputs.

Input Datasets

Three primary datasets are prepared for the R Shiny application, each supporting specific visualization and analysis requirements. The separation of safety data, subject-level efficacy data and visit level efficacy data optimizes performance and ensures appropriate data structures for different output types.

- ***Safety Analysis Dataset (ADAE-like)***

For safety analyses, an intermediate ADAE-style dataset is developed directly in R from raw AE and related source data, mirroring the core structure and variables of a standard ADAE dataset, whilst also including ADSL variables necessary for filtering. This serves as the primary input to the AE module in the R Shiny application.
The dataset includes TEAE flags derived per SAP definitions, analysis start and end dates with protocol-aligned imputation rules, and CTCAE toxicity grades (1–5) alongside seriousness indicators. Causality assessments capture relationships to study treatment (related, not related), while special interest flags identify protocol-defined events such as AESIs, DLTs, and immune-related AEs. Treatment modification flags indicate events leading to dose reduction, interruption, or permanent discontinuation. Population flags ensure consistent denominator definitions across outputs. This structure enables R Shiny safety outputs that align with regulatory-grade ADAE datasets while maintaining flexibility to incorporate study-specific derivation rules and operate directly on raw source data.

- ***Efficacy analysis dataset at Subject Level***

The subject-level dataset supports Waterfall plots, Kaplan-Meier survival curves, ORR tables, and efficacy listings. This dataset contains demographic and baseline characteristics along with population set flags and randomization or registration variables. Disposition status including end-of-treatment date and reason are captured to support treatment duration analyses. The dataset incorporates derived Best Overall Response for both confirmed and unconfirmed assessments, as well as derived time-to-event endpoints including PFS, DOR (unconfirmed), DOR (confirmed), OS, and TTR. For studies employing iRECIST criteria, the dataset additionally includes immune-related response variables such as immune Best Overall Response (iBOR), immune Overall Response Rate (iORR) classifications, and immune Progression-Free Survival (iPFS) endpoints with appropriate handling of unconfirmed progressive disease (iUPD) and confirmed progressive disease (iCPD) events. Concatenated timepoint response data covering Overall, Target, Non-target, and New lesion assessments are included, along with tumor measurement summaries such as sum of diameter change over time, best percent change from baseline, and missing lesion indicators.

- ***Efficacy analysis dataset at Visit Level***

The visit-level dataset supports Spider plots and Swimmer plots that require longitudinal tumor assessment data. This dataset captures visit identifiers and study day for each tumor assessment timepoint. Lesion-level information captures each individual lesion's location and status, organized by Target, Non-Target, New lesion, and Brain lesion categories. Treatment duration variables include TRTEDT for on-treatment periods and overall survival duration for off-treatment follow-up. Key clinical events including death, initiation of new anti-cancer therapy, and response assessments at each visit are recorded to enable comprehensive visualization of patient treatment journeys. For iRECIST-based studies, the visit-level dataset includes immune-related response assessments at each timepoint, capturing iUPD (immune unconfirmed progressive disease) and iCPD (immune confirmed progressive disease) events to support accurate representation of the iRECIST evaluation paradigm in Swimmer plots and longitudinal response tracking.

Analytical Visualization

- ***Safety***

The safety module provides comprehensive adverse event monitoring through multiple integrated outputs designed to support real-time safety surveillance and regulatory reporting. The AE Overview Table delivers a high-level summary of treatment-emergent adverse events (TEAEs) stratified by key safety endpoints including Grade ≥3 events, serious adverse events (SAEs), treatment-related events, events leading to treatment discontinuation, and fatal events. The AE by SOC/PT Table presents adverse event frequencies organized hierarchically by System Organ Class and Preferred Term, while the AE by PT Table ranks TEAEs in descending order of frequency for rapid identification of prevalent events, with configurable frequency thresholds (≥5% or ≥10%) to highlight common toxicities. Subgroup analyses facilitate comparative evaluation of AE profiles across demographic and clinical factors including age group, race, ECOG performance status, dose level, tumor type, and sex, supporting benefit-risk assessment in specific patient populations. The AE Grade Plot provides interactive stacked bar visualizations depicting adverse event severity distributions (Grades 1–5) by Preferred Term, and Detailed AE Listings offer comprehensive patient-level data with dynamic filtering and sorting capabilities by grade, seriousness, Preferred Term, causality/relationship, action taken, and date range, supporting in-depth case review and medical monitoring activities.

- ***Efficacy***

The efficacy module delivers standard oncology visualizations for tumor response and survival analysis. Waterfall plots display best percent change from baseline for each subject along with statistics table by dose level under the plot, enabling rapid assessment of tumor shrinkage patterns across the study population. Spider plots show longitudinal tumor burden trajectories over time, allowing identification of individual response patterns and progression events. For waterfall and spider plots, the visualizations enable interactive exploration of subject-level and visit-level data. Hovering over a subject ID displays the percent change from baseline in sum of diameters (SOD). Clicking the subject ID opens the corresponding subject-level or visit-level listing for detailed review. Swimmer plots visualize treatment duration alongside response milestones, providing an integrated view of treatment exposure and clinical outcomes for each patient. For studies utilizing iRECIST criteria, Swimmer plots additionally display iUPD (immune unconfirmed progressive disease) and iCPD (immune confirmed progressive disease) events, enabling visualization of the iRECIST-specific progression confirmation paradigm where initial progression signals require confirmation at subsequent assessments.

Kaplan-Meier survival curves are generated for PFS, OS, and DOR (both confirmed and unconfirmed), with median survival estimates and confidence intervals displayed in accompanying summary tables. In addition, median follow up time is displayed in KM OS plot, which helps readers understand whether the survival estimates are based on mature data or early observations. Overall Response Rate (ORR) tables present both confirmed and unconfirmed response rates, with a pending confirmation category that tracks subjects whose initial responses are awaiting confirmatory scans per protocol requirement - particularly valuable for interim monitoring in ongoing studies. For iRECIST-based studies, the application additionally generates iPFS (immune Progression-Free Survival) Kaplan-Meier plots and iORR (immune Overall Response Rate) tables, reflecting the modified response assessment rules that allow treatment continuation beyond initial unconfirmed progression. These iRECIST-specific outputs are critical for immunotherapy trials where pseudo-progression may occur, and conventional RECIST criteria may underestimate treatment benefit.

Subject-level and lesion-level efficacy listings provide detailed tumor assessment data for granular review of response evaluations and measurement histories. It could be used for future exploration for biomarker team or stats team.

- ***Global Filtering***

A unified filtering panel affects all visualizations and tables within the application. Users can subset data by tumor type, study phase, treatment cohort, dose level, number of prior lines of systemic anti-cancer therapy, biomarker status, demographic characteristics, and study specific subgroups. Multiple filters can be applied simultaneously to explore specific subpopulations of interest. Filter selections are represented in a reactive subtitle to support reproducibility and enable reconstruction of specific analyses during internal discussions or safety reviews. The reactive architecture ensures that all outputs update instantly when filter selections change, providing seamless exploration of the data.

Validation and Deployment

The validation framework ensures consistency between Shiny outputs and reference SAS-generated TFLs. At the initial stage, the visual check is the major validation method when SDTM/ADaM are not ready. Derivation QC compares calculated values against validated ADaM datasets and production TFLs. Snapshot testing captures expected plot outputs and flags visual regression when code changes occur. Unit tests verify event and censoring logic for time-to-event endpoints against known test cases. Reproducibility logs record data versions, filter selections, and output timestamps for

audit trail documentation. The application is deployed on Posit Connect with role-based access controls, ensuring that only authorized team members can access study data while supporting secure collaboration across functional groups.

RESULTS

Application Performance

The deployed application demonstrates robust performance characteristics with full data refresh taking 10–15 minutes from auto extraction to input datasets for VISTA. The application has been tested with multiple trials up to 400 subjects, handles datasets with thousands of records, and supports concurrent users with multiple simultaneous sessions without degradation in response times.

User Adoption and Feedback

The application has been deployed for multiple oncology trials with positive reception from study teams. Usage statistics show the application is accessed by cross-functional study team members across 8 ongoing trials. The most frequently accessed modules are AE overview tables, AE by PT plot, ORR tables, efficacy plots.
User feedback themes include comments such as "Dramatically reduces time from data extraction to outputs delivery," "Interactive filtering enables exploratory analyses not possible with static reports," "Real-time access supports rapid safety signal evaluation," and "Visualizations are presentation-ready for internal discussion and decision-making meetings."

Impact on Trial Operations

The application has demonstrated significant operational impact across multiple use cases. In a Phase 1 dose-escalation study, real-time DLT monitoring through the application enabled the safety review committee to convene and approve dose escalation.
In another example, the platform enabled the team to evaluate data maturity in real-time, streamlining critical program milestones. Additionally, the concatenated Target, Non-target, and new lesion response data support clinical operations teams in tracking imaging scan completion status and projecting upcoming assessment schedules.

Efficiency Gains

Operating directly on raw data eliminates traditional SDTM/ADaM wait times that can delay insights by days or weeks. The application allows instant re-rendering of safety and efficacy TFLs as new data becomes available, supporting real-time monitoring capabilities. By automating derivations and visualizations, the platform reduces manual programming time by an estimated 80–90% compared to traditional ad-hoc TFL requests. This efficiency enables rapid interim reviews and supports agile medical team discussions without requiring formal programming requests for each exploratory analysis.
The following table summarizes the key differences between the traditional SDTM/ADaM workflow and the R Shiny application approach:

Metric	Traditional SDTM/ADaM Workflow	R Shiny Application - VISTA
Time from data extraction to outputs	10–14 days	<1 day
Enables flexibility by filtering	Limited (requires additional programming update)	Immediate (dynamic filtering)
User interaction	Passive (review static PDFs)	Active (exploratory interface)
Update frequency	Periodic (monthly, quarterly)	Continuous (real-time / daily)

Improved Clinical Decision-Making

The interactive platform significantly enhances clinical decision-making capabilities for study teams across multiple dimensions. Safety physicians can detect emerging toxicity trends early by monitoring AE frequencies and grade distributions as enrollment progresses, with comparative subgroup analyses supporting identification of populations at elevated risk. Real-time efficacy visualizations enable rapid assessment of treatment activity patterns, informing critical trial decisions such as dose optimization, expansion cohort selection, and study continuation or modification strategies.

For proof-of-concept (POC) evaluations and publication planning, the application provides continuous monitoring of key efficacy endpoints (ORR, PFS, DOR, OS), allowing medical teams to assess data maturity and determine optimal timing for go/no-go decisions. In early-phase oncology studies, the ability to visualize response patterns and survival trends in real-time supports identification of target patient populations with favorable benefit-risk profiles, directly informing the design and eligibility criteria for subsequent late-phase trials. For immunotherapy studies using iRECIST criteria, the availability of iPFS curves and iORR tables provides essential insights into treatment benefit that may be obscured by conventional RECIST assessments, particularly in cases of pseudo-progression where continued treatment beyond initial progression signals may yield clinical benefit.

Collaboration

The web-based platform supports efficient cross-functional review by providing a shared analytical environment accessible to all authorized team members. Clinical operation leads, safety physicians, biostatisticians, statistical programmers, medical leads, data scientists, biomarker and PK team members can access the same visualizations simultaneously, enabling productive discussions during team meetings and safety reviews. The ability to apply filters and explore subgroups in real-time during meetings eliminates the need for follow-up programming requests and accelerates decision-making cycles.

Key Advantages Over Traditional Approaches

The Safety & Efficacy visualization tool - VISTA provides several strategic advantages compared to traditional workflows and commercial tools.

- ***Agile and Realtime***

  The platform can meet real-time requirements for medical monitoring, enabling continuous safety surveillance as data accumulates without waiting for periodic data cuts. By operating independently from SDTM and ADaM pipelines, the tool prevents repeated reruns that could impact routine formal delivery generation, safeguard regulatory submission timelines and effectively reduce pipeline contention.

- ***Flexibility***

  Users benefit from flexible data filtering that allows dynamic exploration across multiple dimensions simultaneously, enabling rapid investigation of subpopulations without additional programming requests. The R Shiny interface provides more intuitive and visually accessible results compared to static outputs, improving comprehension during cross-functional reviews and enabling stakeholders with varying technical backgrounds to engage with the data.

- ***SAP-Aligned***

  Unlike data management tools such as Elluminate or Spotfire, this platform incorporates derived efficacy endpoints including ORR, iORR, PFS, iPFS, DOR, OS, Time to Response, and other oncology-specific metrics aligned with SAP definitions. This integration of derived endpoints within the visualization environment eliminates the gap between data review and efficacy analysis that exists in commercial data management platforms. The support for both RECIST and iRECIST criteria ensures the platform remains applicable across conventional oncology trials and modern immunotherapy studies.

- ***Automation***

  The application supports automated daily execution cycles, ensuring key team members have access to current data without manual intervention. This scheduled refresh capability maintains data currency while minimizing operational burden on programming teams. Additionally, the tracker serves as an alternative method to validate safety and efficacy outputs, providing independent verification of derived endpoints against primary SAS-generated TFLs and strengthening overall quality assurance processes.

DISCUSSION

ELIMINATING SDTM/ADAM DEPENDENCY

Processing raw data directly provides substantial operational benefits for clinical trial monitoring. Teams gain faster insights because visualizations update as soon as raw data files are refreshed, without waiting for SDTM and ADaM transformation cycles. The approach reduces reliance on SAS-based workflows for exploratory analyses, freeing validated SAS programming resources to focus on regulatory deliverables. Most importantly, the raw data approach aligns with real-time operational needs for safety monitoring and clinical decision-making, where delays of days or weeks can impact patient safety and trial strategy.

Technical and Methodological Challenges

Several technical challenges were addressed during development and deployment.
Data inconsistency across studies was resolved through standardized specifications that define consistent variable names, formats, and derivation rules, enabling the application to process multiple trials without code modifications.

Phase 1 oncology studies presented unique challenges due to non-standardized designs. Unlike later-phase trials with uniform cohorts, Phase 1 dose-escalation and expansion studies involve heterogeneous cohorts with varying treatments, staggered enrollment, and evolving evaluation rules such as DLT windows and response schedules. This required study-specific customization of filter options to accommodate diverse cohort definitions, dose levels, and analysis of populations.

An important consideration was establishing appropriate expectations regarding regulatory use. While the application generates outputs that mirror regulatory TFLs in structure, these visualizations serve operational and exploratory purposes rather than formal regulatory submissions. Systematic labeling identifies outputs as "For internal use only" distinct from validated datasets for regulatory agencies.

Limitations

While the R shiny app - VISTA provides substantial benefits for real-time monitoring and exploratory analysis, several limitations should be acknowledged. The platform is designed for operational decision-making and is not intended to replace validated regulatory submissions or final analysis datasets. Processing raw source data into analysis-ready formats involves derivations similar to ADaM dataset creation. To avoid redundant programming effort, the number of intermediate analysis datasets developed for VISTA is limited, as these derivations will ultimately be reproduced during formal ADaM development. Output quality depends on the completeness and accuracy of raw source data, which may contain inconsistencies or missing values prior to formal data cleaning cycles. The application requires ongoing maintenance to accommodate protocol amendments, new studies, and evolving regulatory guidance. Additionally, user training is essential to ensure proper interpretation of outputs and understanding of the distinction between exploratory Shiny visualizations for internal discussion and validated TFLs intended for regulatory submission.

Scalability

The modular framework supports scalability across multiple dimensions. The architecture accommodates multiple tumor types and dose levels within a single application instance, enabling portfolio-wide deployment across related studies. Future enhancements are planned for biomarker integration to support translational analyses and demographic modules for ongoing study enrollment monitoring. The component-based design allows incremental addition of new visualization types and analytical capabilities as requirements evolve.

CONCLUSION

We developed a real-time R Shiny Safety & Efficacy Tracker – VISTA that generates dynamic TFLs from raw data, aligns with SAP logic, and bypasses SDTM/ADaM dependencies. This tool accelerates clinical insights, supports adaptive trial strategies, enhances collaboration, and improves operational efficiency in oncology trials. The platform supports both RECIST and iRECIST response criteria, providing iORR tables, iPFS Kaplan-Meier plots, and Swimmer plots with iUPD/iCPD events for immunotherapy studies. By providing capabilities for real-time medical monitoring, automated execution, and serving as an alternative validation method for safety and efficacy outputs, the platform addresses critical gaps in traditional clinical trial workflows. The successful implementation demonstrates that interactive R Shiny applications can complement traditional SAS-based regulatory workflows while meeting the urgent needs of clinical teams for timely safety and efficacy information. It represents a scalable model for future interactive clinical analytics across the pharmaceutical development portfolio.

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ACKNOWLEDGMENTS

We acknowledge the contributions of statistical programming, biostatistics, safety, medical, clinical operations, data management, and cross-functional teams whose engagement and feedback helped shape the development and adoption of VISTA.

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