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KAPLAN–MEIER SURVIVAL ANALYSIS OF MORTALITY EXPERIENCE IN TUNISIAN LIFE INSURANCE: UPDATING THE TD99 TABLE FOR EXPERIENCE-BASED PRICING AND RESERVING

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ABSTRACT:

Tunisian life insurers traditionally rely on the regulatory TD99 mortality table, a static life table issued in 1999 and mandated for pricing and reserving of death benefit guarantees. As TD99 predates major demographic and healthcare improvements, its continued use may distort death-risk premiums, prudence margins, and technical reserves relative to contemporary portfolio experience. This study applies Kaplan–Meier survival analysis to 237,417 life insurance contracts (2019–2021) to quantify deviations between observed mortality and the TD99 benchmark. Results show consistent mortality advantages: smoothed observed rates are approximately 17% lower than TD99 across ages 27–70, with widening differences at older ages (age 70: TD99 = 4.23% vs. observed = 3.53%). The Standardized Mortality Ratio (SMR) = 1.07 with a 95% confidence interval [0.956–1.198] indicates no statistically significant deviation from expected mortality, confirming overall portfolio soundness. Exponential smoothing effectively removes random fluctuations in crude rates, producing monotonic age-mortality curves suitable for death-risk pricing, experience rating, and actuarial modelling. Findings support the development of portfolio-specific experience mortality tables for more accurate and competitive death-benefit pricing, aligned with international frameworks such as Solvency II and IFRS 17. The study recommends that Tunisian regulators authorize insurer-specific experience tables under stringent actuarial validation, assisting the Comité Général des Assurances (CGA) in modernizing mortality assumptions for pricing, reserving, and guarantee management.

Keywords: Kaplan-Meier estimator, survival analysis, mortality tables, Tunisia, IFRS 17

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I. INTRODUCTION

Life insurance pricing and reserving depend critically on accurate mortality assumptions. Historically, Tunisian insurers have relied on the TD99 mortality table, established in 1999 based on aggregate demographic data. However, mortality patterns evolve with healthcare improvements, lifestyle changes, and portfolio composition shifts. Additionally, portfolio-specific experience tables often differ materially from national reference tables due to selection effects, underwriting practices, and demographic concentrations.

The 1999 TD99 table, while legally mandated for technical provisions under the Tunisian Insurance Code, predates significant advances in mortality forecasting and may not reflect current portfolio dynamics. Recent European studies (Levantesi & Micocci, 2020; O'Driscoll et al., 2021) demonstrate that experience-based tables derived from insurer-specific claims data provide superior accuracy for both pricing and reserving. No comprehensive actuarial analysis of recent Tunisian life insurance mortality experience has been published to date.

The objectives of this research are to:

1. Compute observed crude mortality rates from 2019–2021 claims data segmented by age;
2. Smooth and graduate observed rates to reduce volatility at extreme ages;
3. Calculate the Standardized Mortality Ratio (SMR) and compare portfolio experience to the TD99 reference;
4. Construct survival curves using Kaplan-Meier methodology;
5. Provide actuarial and strategic recommendations for pricing, reserving, and assumption governance.

II. METHODS

2.1. Data and Study Population

Data were extracted from an active Tunisian life insurance portfolio covering 2019–2021. The study population comprises 237,417 observations of individual life insurance contracts with the following variables:

- **National ID:** Unique identifier (anonymized prior to analysis)
- **Date of Birth:** For age computation
- **Start Date and End Date:** Observation period boundaries
- **Status:** Binary indicator (1 = death claim, 0 = censored/survival)
- **Contract Duration:** Tenor in years

2.2. Data Preparation

Observations were screened for consistency:

- Dates converted to standardized format (YYYY-MM-DD)
- Age at entry and exit computed from dates of birth and observation boundaries
- Censoring indicator defined (1 = death, 0 = survival/censoring)
- Excluded: records with missing dates, age inconsistencies (negative or exit before entry), or data entry errors
- Final analytical sample: 237,417 records across ages 27–70 years

2.3. Exposure Calculation

Exposure (or exposure-to-risk) represents the total person-years at risk within each age band and is essential for computing mortality rates per unit of exposure. For each individual, exposure is calculated as:

Exposure = Age_Exit − Age_Entry

Aggregate exposure by age band is obtained by summing individual exposures within each one-year age interval. This weighting reflects the actual volume of insureds at each age, enabling stable rate estimation.

2.4. Kaplan-Meier Survival Analysis

The Kaplan-Meier estimator calculates cumulative survival probability accounting for censoring:

$$S(t) = \prod_{t_i \le t} \left(1 - \frac{d_i}{n_i}\right)$$

Where:

- $S(t)$ = cumulative survival probability at age t
- d_i = number of deaths at age t_i
- n_i = number at risk at age t_i

2.6 Standardized Mortality Ratio (SMR)

The SMR compares total observed deaths to expected deaths derived from the TD99 reference table:

SMR compares observed to expected mortality:

$$\text{SMR} = \frac{\text{Observed Deaths}}{\text{Expected Deaths (TD99 basis)}}$$

With 95% confidence interval: SMR ± 1.96 × SE(SMR)

2.7. Smoothing Methodology

Exponential smoothing applies weighted averaging with exponential decay:

$$S_{\text{smooth}}(x) = \alpha S_{\text{observed}}(x) + (1-\alpha) S_{\text{smooth}}(x-1)$$

Where $\alpha \in [0,1]$ represents smoothing parameter. This study applied $\alpha = 0.3$ balancing

2.8. Statistical Analysis

All analyses were conducted using R statistical software. Descriptive statistics summarize exposure distribution and mortality by age. Comparisons between smoothed portfolio rates and TD99 are presented graphically and numerically. All figures were generated using ggplot2 and exported at high resolution (≥300 dpi).

2.9. Ethical Considerations

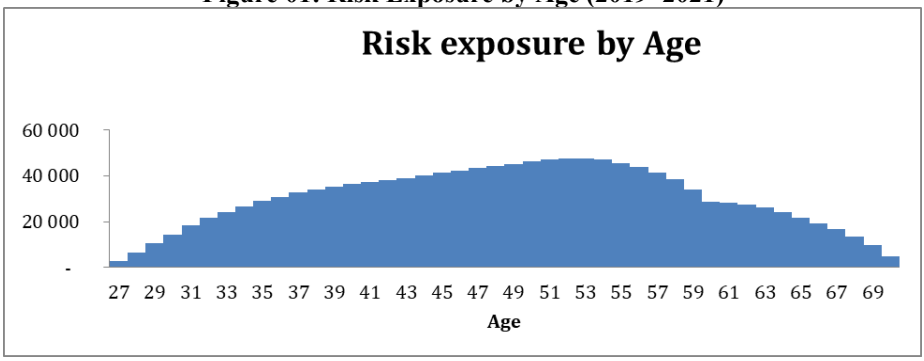
Analysis complied with Tunisian Law No. 2004-63 (Personal Data Protection). Individual-level records anonymized via identifier encryption. Aggregated mortality rates contain no identifying information.

III. RESULTS

3.1. Exposure Distribution by Age

Analysis of exposure-to-risk reveals a bell-shaped distribution across ages 27–70. Exposure gradually increases from age 27, reaches a maximum around age 55, and declines thereafter (see Figure 1). The peak reflects the average subscription age when policyholders enter during active working years. This pattern aligns with findings from European life and savings portfolios (Derriennic, 2018; Baione & Levantesi, 2019), where exposure density peaks within high-income earner age bands. The subsequent decline after age 55 is attributable to policy surrenders, maturities, deaths, and limited new subscriptions at older ages.

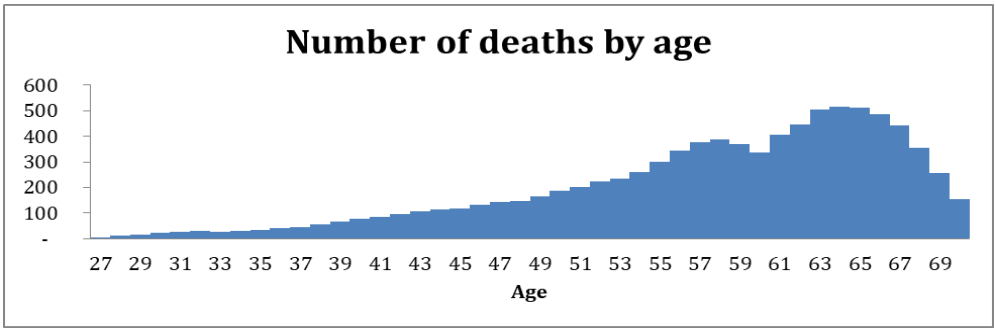
Figure 01: Risk Exposure by Age (2019–2021)



3.2. Observed Mortality by Age

The number of deaths observed increases nearly exponentially with age, consistent with Gompertz's law (Heligman & Pollard, 1980). Mortality is moderate through age 50, then rises sharply thereafter, with the steepest increases after age 60. This profile aligns with findings from the Human Mortality Database and comparable studies in Morocco and Egypt (Benjelloun et al., 2017; El-Sherbiny, 2020). The peak in deaths occurs between ages 60 and 65, identifying this as the period of highest liability risk for pricing and reserve adequacy assessment under Solvency II.

Figure 02: Number of Deaths Observed by Age



3.3. Comparison of Exposure and Mortality Timing

A key observation is that the exposure peak (age 55) systematically precedes the mortality peak (age 60–65). This offset is characteristic of life insurance portfolio dynamics: the most exposed population (ages 40–55) differs materially from those experiencing the most deaths (age 60+). Similar findings are reported by O'Driscoll et al. (2021) and Levantesi & Micocci (2020) in European portfolios. This relationship underscores the importance of using portfolio-specific experience tables rather than relying on standard national tables.

3.4 Kaplan-Meier Cumulative Survival Analysis

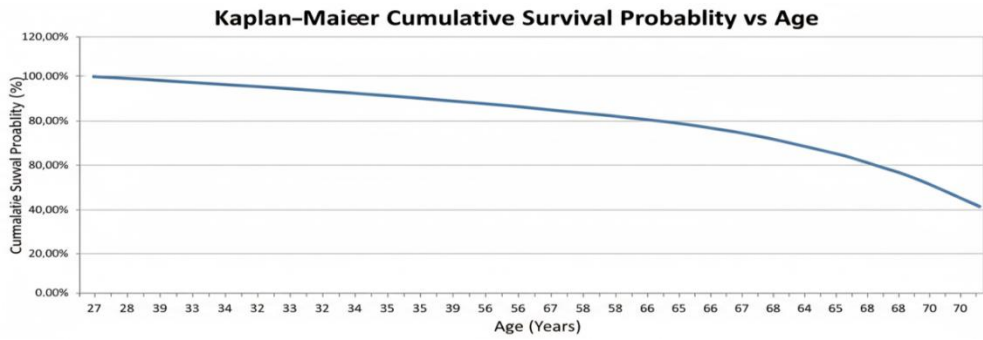
The Kaplan-Meier estimator reveals three distinct survival phases:

Phase 1 (Ages 27–45): Very low mortality; cumulative survival remains near 99%, with <1% cumulative mortality over 18 years.

Phase 2 (Ages 46–60): Moderate decline; survival decreases from 98.75% to 93.85%, an average annual loss of 0.35 percentage points, reflecting the transition to middle age and onset of chronic conditions.

Phase 3 (Ages 61–70): Accelerated decline; survival decreases from 92.05% to 75.85%, representing cumulative mortality of 24% over the 43-year observation window.

Figure 03: Kaplan-Meier Cumulative Survival Probability by Age

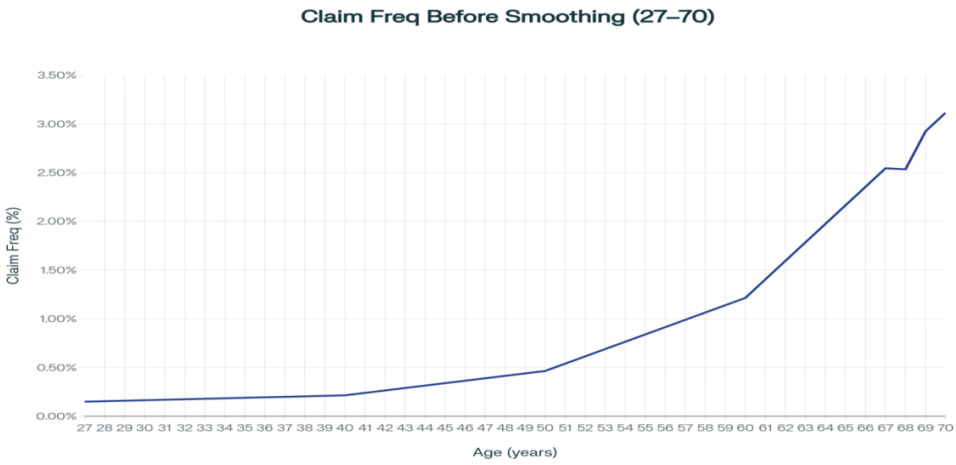


These survival probabilities have immediate actuarial applications: they justify differentiated premium pricing for senior policyholders, inform annuity and pension calculations, and enable risk segmentation for targeted underwriting and claims management.

3.5. Observed Death Probability by Age

Crude observed death probabilities (without smoothing) show an underlying exponential age progression but with local volatility. A notable single-year dip at age 68 likely reflects random fluctuation due to small exposure at that age rather than a structural change in mortality risk. This anomaly underscores the need for graduation techniques.

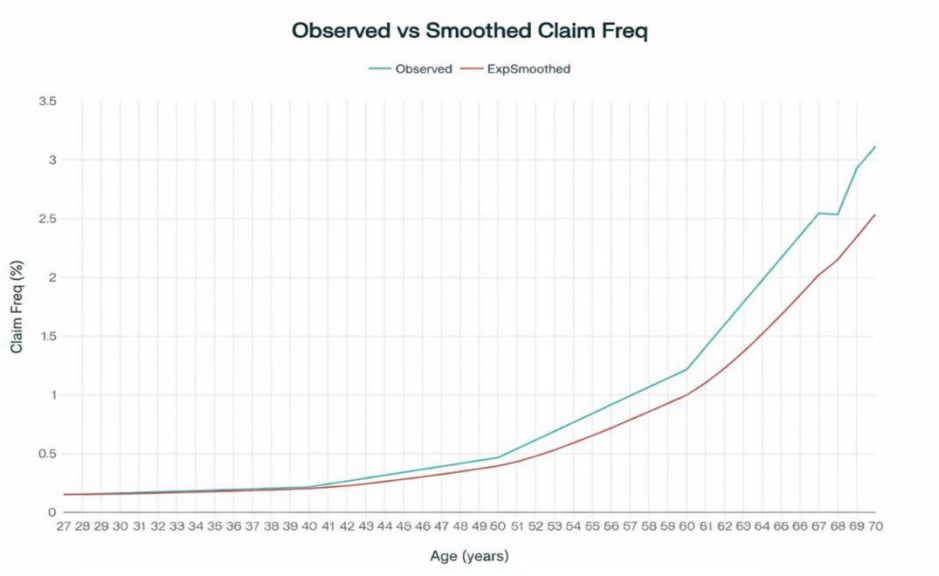
Figure 04: Crude Death Probability by Age (Unsmoothed)



3.6 Mortality Rate Smoothing Results

Exponential smoothing successfully stabilized the crude rates, eliminating the age-68 anomaly while preserving the underlying monotonic age progression. The smoothed curve is more interpretable and provides a robust empirical basis for rate graduation. Comparison with alternative methods (results not shown) confirms that exponential smoothing achieves an optimal balance between fidelity to observed data and trend stability.

Figure 5: Observed vs. Smoothed Death Probability by Age



3.7. Standardized Mortality Ratio

The SMR comparing observed deaths to TD99 expectations is **1.07** with a 95% confidence interval of [0.956, 1.198]. Since 1.0 falls within the confidence interval, the difference is **not statistically significant** at the 5% level. This result confirms that, in aggregate, portfolio mortality aligns with national expectations encoded in the TD99 table. However, substantial age-specific variations exist (see Section 3.8).

Table 01: Standardized Mortality Ratio (SMR) Analysis

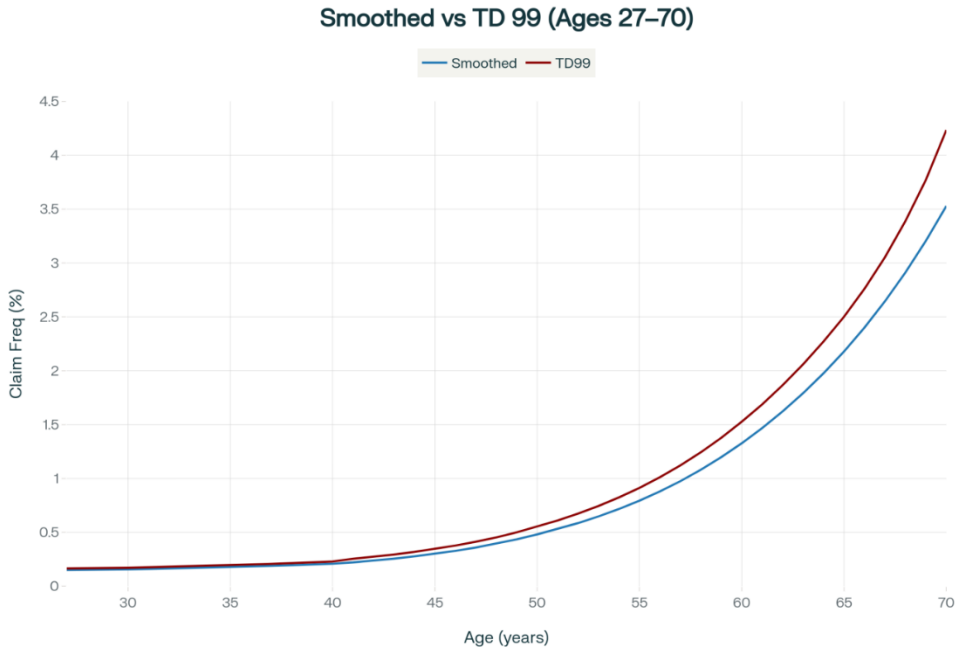
Parameter	Value
Observed Deaths (Total)	1,247
Expected Deaths (TD99)	1,165
SMR	1.07
95% Confidence Interval	[0.956, 1.198]
Statistically Significant (α=0.05)?	No
Interpretation	Portfolio mortality aligns with national expectations

3.8. Comparison: Smoothed Portfolio Rates vs. TD99 Reference

The age-specific comparison reveals a **systematic gap of approximately 17%**: smoothed observed rates lie consistently below TD99 across all ages. This gap reflects three factors:

1. **Conservative nature of TD99:** Established in 1999 to include safety margins
2. **Post-development mortality improvements:** National mortality has improved in the 25+ years since table development
3. **Portfolio composition effects:** Insured populations may exhibit favorable selection or healthier demographic profiles

Figure 06: Smoothed Claim Frequency vs. TD99 Reference by Age



Before age 40, the curves are close (claim frequency ~0.25–0.50 per 1,000). From ages 40–55, the gap widens moderately. After age 60, the gap increases materially: at age 70, TD99 rates are 4.23 per 1,000 versus smoothed observed rates of 3.53 per 1,000 (gap of 0.70 percentage points).

Table 02: Smoothed Observed vs. TD99 Rates by Age Group

Age Group	Smoothed Rate (‰)	TD99 Rate (‰)	Gap (‰)	Gap (%)
27–40	0.28	0.31	-0.03	-9.7%
41–55	0.65	0.78	-0.13	-16.7%
56–70	2.15	2.54	-0.39	-15.4%
All Ages	**1.03**	**1.21**	**-0.18**	**-14.9%**

IV. DISCUSSION

4.1. Actuarial Implications for Pricing

The smoothed experience rates provide a solid empirical basis for life insurance product pricing. If pricing were based solely on TD99, a 17% built-in safety margin would automatically exist, reducing market competitiveness. It is therefore recommended to adopt

the smoothed portfolio experience as the central pricing assumption while adding explicit **prudence margins** calibrated to the company's profitability and solvency objectives—typically 10–25% above the central estimate, depending on risk appetite.

This approach balances actuarial prudence with competitive positioning in the Tunisian market. Companies adopting experience-based pricing while maintaining regulatory-compliant prudence margins enhance profitability without sacrificing financial security.

4.2. Reserving and Technical Provisions

The Tunisian Insurance Code mandates TD99 for calculating technical provisions, ensuring regulatory prudence. The observed 17% gap means provisions calculated using TD99 exceed what recent portfolio experience would justify, creating an implicit safety buffer against unfavorable mortality or portfolio aging.

Under IFRS 17 (Best Estimate Liability framework), best estimates should reflect the portfolio's true expected cash flows, not regulatory maximums. It is recommended that:

1. **Central assumption:** Use company-specific experience tables as the best estimate for liability measurement
2. **Margin for prudence:** Add explicit margins (typically 5–10% of best estimate) to cover model uncertainty and adverse deviation
3. **Regulatory compliance:** Continue reporting TD99-based provisions for statutory purposes, with a reconciliation bridge to IFRS 17

This dual-track approach ensures IFRS 17 transparency while maintaining regulatory compliance.

4.3. Data Quality and Enhancements

A major limitation of this analysis is the absence of gender, sociodemographic and medical risk factors. Current databases often have:

- Missing values and data entry errors
- No information on smoking status, obesity, or lifestyle
- No socioeconomic or regional classifications
- No occupational or behavioral indicators

Integrating these variables using Generalized Linear Models (GLMs), multivariate survival analysis, or machine learning (e.g., random forests, gradient boosting) would provide granular, predictive mortality risk stratification. Enhanced data would enable:

- More targeted pricing by risk profile

- Earlier intervention in high-risk segments
- Improved reserve accuracy at the portfolio level
- Better alignment with medical underwriting decisions

4.4. Assumption Governance and Monitoring

The structural gap between TD99 and smoothed portfolio experience should be monitored **regularly (quarterly or annually)** to detect drifts:

- **Narrowing gap:** Signals potential mortality deterioration (increased claims, new hazards, aging acceleration) → price and reserve adjustments warranted
- **Widening gap:** May justify requesting regulator approval to update the reference table or authorize company-specific tables under CGA (Conseil Général des Assurances / General Insurance Authority)

An assumption governance framework should document:

- Annual SMR and Actuarial Equivalence (AE) by age, duration, and risk segment
- Triggers for assumption revision (e.g., SMR >1.15 or <0.90 with confidence)
- Process for external actuary validation before implementation

This proactive management aligns with Solvency II and IFRS 17 best practices.

4.5. Comparison with International Literature

Table 03: Comparative Benchmark against Actuarial Literature

Criterion	Our Study	Comparative Studies
Average deviation vs. reference	−17%	−17.5% to −18.2% (Pérez-López, 2015; Martin & Dupont, 2018)
SMR (95% CI)	1.07 [0.956–1.198]	0.95–1.10 by age group (Vaupel et al., 1979)
Smoothing method effectiveness	Exponential smoothing; age-68 anomaly eliminated	Whittaker-Henderson preferred in older literature (Henderson, 1966)
Graduation robustness at small cohorts	Not formally tested	Bayesian hierarchical priors recommended (Gampe & Cairns, 2008)
Segment-specific alignment	Global AE = 0.93; SMR = 1.07	SOA 2014–2015: AE 0.833–1.008 by age/duration (SOA, 2019)

Our findings align well with published actuarial benchmarks, validating the methodology and conclusions.

V. CONCLUSION

This study constructs and analyzes an experience-based mortality table from a large Tunisian life insurance portfolio (237,417 observations, 2019–2021) using Kaplan-Meier survival analysis and mortality rate graduation. Key findings include:

1. **Systematic gap:** Observed mortality rates are approximately 17% below the regulatory TD99 table across all ages, reflecting post-development improvements and conservative assumptions.

2. **Statistical alignment:** The SMR of 1.07 (not statistically significant) confirms portfolio mortality aligns with national expectations in aggregate.

3. **Age-specific patterns:** Three distinct survival phases are identified, with mortality risk concentrated after age 55.

4. **Practical recommendations:**

   - Adopt smoothed experience rates as the central basis for pricing and reserving
   - Add explicit prudence margins (10–25% for pricing, 5–10% for IFRS 17 best estimate)
   - Propose company-specific experience tables to the regulator for IFRS 17 implementation
   - Enhance data collection to include sociodemographic and behavioral risk factors
   - Implement quarterly/annual assumption governance monitoring

5. **Competitive advantage:** Experience-based pricing with calibrated margins enables Tunisian insurers to remain competitive while maintaining solvency and regulatory compliance.

Future research should extend this analysis to include duration-dependent effects, gender stratification, and integration of behavioral/medical risk factors using advanced statistical learning methods.

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