

PSA Trends and Clinical Outcomes Following Radiotherapy Combined with Androgen Deprivation Therapy for Prostate Cancer: A Single-Centre Retrospective Cohort Study from Saudi Arabia

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Abstract

Background

Combined external-beam radiotherapy and androgen deprivation therapy (ADT) is standard treatment for men with intermediate- to high-risk prostate cancer, but outcome data from the Gulf region remain limited despite a rising regional disease burden. We evaluated longitudinal PSA response, treatment-related morbidity, and oncological outcomes in patients treated with curative-intent radiotherapy plus ADT, characterising PSA kinetics over the first nine months of treatment and identifying clinical predictors of the PSA trajectory.

Methods

In this retrospective cohort study at King Abdulaziz Medical City, Riyadh, we included all adult patients with prostate cancer who received radiotherapy combined with ADT and had complete treatment and follow-up records. Demographic, clinical, and treatment data were extracted from electronic medical records, with serial PSA recorded at baseline and at 3, 6, and 9 months. Changes in PSA from baseline were assessed with the paired Wilcoxon signed-rank test, and a linear mixed-effects model (random intercept per patient; fixed effects for time, age, Gleason group, and metastatic status; PSA $\log_{10}[\text{PSA} + 1]$ -transformed) was used to identify predictors of longitudinal PSA levels.

Results

Seventy-four patients were included (median age 68.0 years, IQR: 63.0–75.0; median PSA at diagnosis 17.3 ng/mL, IQR: 9.3–33.0), 64.9% with Gleason group 4–5 disease. Most received hypofractionated radiotherapy (median 60 Gy in 20 fractions) with a single ADT cycle (90.4%), predominantly leuprolide (91.8%). PSA fell progressively at every interval (all $p < 0.001$): median reductions of 91.9%, 99.2%, and 99.7% from baseline at 3, 6, and 9 months, with the proportion achieving a $\geq 50\%$ reduction rising from 73.2% to 93.0% over the same period; median PSA nadir was 0.028 ng/mL (IQR: 0.024–0.560). On adjusted mixed-effects modelling, reductions at each time point remained significant independent of age and Gleason group ($\beta = -0.81$ to -1.13 versus baseline, all $p < 0.001$), while metastatic disease at presentation predicted higher longitudinal PSA levels. Disease recurrence occurred in 5.4% of patients, with a median time to recurrence of 68.5 months; treatment-related toxicity was low, with urinary incontinence and erectile dysfunction each affecting fewer than 7% of patients at 12 months.

Conclusions

In this predominantly high-risk, real-world cohort, combined radiotherapy and ADT produced rapid, deep, and durable PSA suppression with low toxicity and low biochemical recurrence, irrespective of baseline Gleason grade. These findings support the effectiveness and tolerability of this regimen outside the trial setting and provide PSA kinetic benchmarks from an underrepresented population that may complement randomised evidence, though prospective data incorporating PSMA-PET-based surveillance are needed to confirm whether early deep response translates into durable survival benefit.

Introduction

Prostate cancer is one of the most commonly diagnosed cancers in men, ranging from localised low-risk disease to aggressive high-risk presentations. For men with intermediate- or high-risk disease, combining external-beam radiotherapy with androgen deprivation therapy (ADT) has become the standard of care, with randomised trials consistently demonstrating improvements in biochemical control [1], disease-free survival [2], and overall survival [3]. The global burden of prostate cancer continues to increase, driven largely by ageing populations, with the majority of cases occurring in men over the age of 65 [4]. Despite widespread implementation of prostate-specific antigen (PSA) screening, a substantial proportion of patients present with intermediate- or high-risk disease requiring definitive multimodal therapy.

The rationale for this combination is well established: ADT reduces tumour volume and sensitises cancer cells to radiation by impairing DNA repair mechanisms [5], while radiotherapy provides targeted local disease control. Landmark trials have shaped current practice. RTOG 94 – 08 showed that adding four months of ADT to radiotherapy improved 10-year overall survival from 57% to 62% and reduced biochemical failure rates compared with radiotherapy alone [1]. RTOG 92 – 02 demonstrated that extending ADT beyond four months further reduces disease progression, local and distant relapse, and biochemical recurrence, with an overall survival advantage confined to men with Gleason 8–10 tumours [6]. Long-term ADT combined with radiotherapy in the EORTC 22863 trial doubled disease-free survival and improved overall survival compared with radiotherapy alone [3]. Meta-analyses indicate that adding short-course ADT modestly reduces biochemical failure and provides a modest survival benefit when combined with radiotherapy [7, 17].

PSA response following combined treatment has emerged as a key prognostic marker, with lower post-treatment PSA nadirs associated with better long-term disease control. Large registries and clinical series report that deeper nadirs and sustained suppression predict superior long-term biochemical control and prostate-cancer-specific survival. Zelefsky et al. found that a 2-year PSA nadir ≤ 1.5 ng/mL after radiotherapy independently predicted improved distant-metastasis-free and cause-specific survival [8]. Critz et al. further reported that patients achieving a nadir ≤ 0.2 ng/mL remained disease free at 10 years, whereas those with PSA > 1 ng/mL experienced treatment failure [19]. These findings underscore that lower post-treatment PSA nadirs are strongly associated with durable disease control.

In Saudi Arabia and the broader Gulf region, the incidence of prostate cancer has been rising, yet comprehensive data on treatment outcomes and disease trajectories remain limited. This is particularly relevant given the high prevalence of metabolic comorbidities, which may influence both treatment tolerance and oncological outcomes [14].

Accordingly, the present study aimed to evaluate longitudinal PSA response, treatment-related morbidity, and oncological outcomes in patients with prostate cancer treated with curative-intent radiotherapy and ADT at King Abdulaziz Medical City, Riyadh. We specifically characterised PSA kinetics over the first nine

months of treatment, identified clinical and demographic predictors of PSA trajectories using a linear mixed-effects model, and assessed rates of recurrence and treatment-related toxicity.

Methods

Study Setting and Participants

This retrospective observational cohort study was conducted at King Abdulaziz Medical City (KAMC-R), Riyadh, Saudi Arabia. The study included all adult patients diagnosed with prostate cancer who received androgen deprivation therapy combined with radiotherapy. Patients were excluded if they had incomplete treatment or follow-up records, were treated outside the study centre, or were managed with surgery alone without ADT or radiotherapy. Given the retrospective design and the inclusion of the entire eligible cohort, no formal sample size calculation was performed; 74 patients met all inclusion criteria and were included in the analysis.

Data Collection

Data were extracted retrospectively from electronic medical records using a standardised data collection form. Variables collected included patient demographics (age at diagnosis, body mass index), clinical features (PSA at diagnosis, Gleason group, tumour stage, nodal and metastatic status, comorbidities), treatment details (radiotherapy dose and fractionation, ADT agent and duration, use of additional antiandrogens), serial PSA measurements at baseline and at 3, 6, and 9 months, and clinical outcomes including disease recurrence, urinary incontinence, erectile dysfunction, and mortality.

Statistical Analysis

Data were analysed using RStudio (version 2024.9.1.394; Boston, MA, USA) with R version 4.4.2. Continuous variables were summarised as medians with interquartile ranges (IQR); categorical variables were presented as frequencies and percentages. Changes in PSA levels from baseline to 3, 6, and 9 months were assessed using the paired Wilcoxon signed-rank test. A linear mixed-effects model with a random intercept for each patient was used to evaluate factors associated with longitudinal PSA levels; fixed effects included time (modelled as a categorical variable), age at diagnosis, Gleason group, and metastatic status, with PSA values log-transformed ($\log_{10}[\text{PSA} + 1]$) prior to analysis. All statistical tests were two-sided, and a p-value of less than 0.05 was considered statistically significant.

Ethical Approval

The study was approved by the Institutional Review Board of King Abdullah International Medical Research Center (KAIMRC). Given the retrospective nature of the study, the requirement for informed consent was waived.

Results

Demographic and Clinical Characteristics

The study included 74 patients who underwent curative radiotherapy plus androgen deprivation therapy (ADT). The median age at diagnosis was 68.0 years (IQR: 63.0–75.0), with a median BMI of 29.0 kg/m² (IQR: 26.2–32.9) and a median PSA at diagnosis of 17.3 ng/mL (IQR: 9.3–33.0). The predominant Gleason group was group 4, accounting for 36.5% of patients, followed by group 5 (28.4%). Hypertension was the most prevalent comorbidity (n = 46, 62.2%), followed by diabetes mellitus (n = 44, 59.5%) and other comorbidities (n = 43, 58.1%).

Computed tomography of the chest, abdomen, and pelvis (CT CAP) was the most frequently used staging modality (n = 66, 89.2%), followed by bone scan (n = 58, 79.5%), MRI (n = 37, 50.7%), and PSMA-PET scan (n = 30, 40.5%). The median prostate volume was 44.5 mL (IQR: 34.0–67.0), most commonly assessed by transrectal ultrasound (n = 34, 69.4%). Regarding tumour staging, T2 was the predominant stage (n = 37, 52.9%), while most patients had N0 nodal disease (n = 65, 87.8%) and were non-metastatic (M0; n = 60, 81.1%). Among the 14 patients with metastatic disease (M1, 18.9%), bone was the most common site of involvement (n = 10, 13.5%), followed by lymph nodes (n = 9, 12.2%) and visceral organs (n = 3, 4.1%). Family history of prostate cancer and tobacco use were infrequent, recorded in 2.7% and 4.1% of patients, respectively (Table 1).

Table 1: Demographic and clinical characteristics

Characteristic	n (%) or Median (IQR)
Age at Diagnosis (years)	68.0 (63.0–75.0)
BMI at Diagnosis (kg/m ²)	29.0 (26.2–32.9)
PSA at Diagnosis (ng/mL)	17.3 (9.3–33.0)
Gleason Group at Diagnosis	
Group 1	4 (5.4%)
Group 2	12 (16.2%)
Group 3	10 (13.5%)
Group 4	27 (36.5%)
Group 5	21 (28.4%)
Comorbidities	
Hypertension	46 (62.2%)
Diabetes Mellitus	44 (59.5%)
Other	43 (58.1%)
Staging Modality	
CT Chest/Abdomen/Pelvis	66 (89.2%)
Bone Scan	58 (79.5%)
PSMA-PET Scan	30 (40.5%)
MRI	37 (50.7%)
Prostate Volume (mL)	44.5 (34.0–67.0)
Volume Assessment Modality	
Transrectal Ultrasound	34 (69.4%)
MRI	13 (26.5%)
Digital Rectal Examination	2 (4.1%)
Tumour Stage	
T1	19 (27.1%)
T2	37 (52.9%)
T3	12 (17.1%)
T4	2 (2.9%)

Characteristic	n (%) or Median (IQR)
Nodal Status	
N0	65 (87.8%)
N1	9 (12.2%)
Metastatic Status	
M0	60 (81.1%)
M1	14 (18.9%)
Site of Metastasis (among M1 patients)	
Bone	10 (13.5%)
Lymph Nodes	9 (12.2%)
Visceral Organs	3 (4.1%)
Other	5 (6.8%)
Risk Factors	
Family History of Prostate Cancer	2 (2.7%)
Current or Former Smoker	3 (4.1%)

IQR = interquartile range. Values are presented as median (IQR) for continuous variables and n (%) for categorical variables.

Treatment Characteristics

Active surveillance prior to definitive treatment was documented in 23.0% of patients (n = 17). The median radiotherapy dose was 60 Gy (IQR: 60–60), delivered over a median of 20 fractions (IQR: 20–20).

Most patients received a single ADT cycle (n = 66, 90.4%), with leuprolide being the most commonly used initial agent (n = 67, 91.8%) at a median dose of 22.5 mg (IQR: 22.5–22.5). A second ADT cycle was administered in a minority of patients (n = 7, 9.6%), exclusively using goserelin at a median dose of 10.8 mg.

Among patients who received antiandrogen therapy, the most commonly used agent was bicalutamide (n = 36, 48.6%), followed by abiraterone (n = 6, 8.1%), enzalutamide (n = 2, 2.7%), and apalutamide (n = 1, 1.4%) (Table 2).

Table 2: Treatment characteristics

Characteristic	n (%) or Median (IQR)
Active Surveillance Prior to Treatment	17 (23.0%)
Radiotherapy Dose (Gy)	60.0 (60.0–60.0)
Number of Fractions	20.0 (20.0–20.0)
Number of ADT Cycles	
One	66 (90.4%)
Two	7 (9.6%)
First ADT Agent	
Leuprolide	67 (91.8%)
Goserelin	6 (8.2%)
First ADT Dose (mg)	22.5 (22.5–22.5)
Second ADT Agent (n = 7)	
Goserelin	7 (100.0%)
Second ADT Dose (mg)	10.8 (10.8–10.8)
Antiandrogen Therapy	
Bicalutamide	36 (48.6%)
Abiraterone	6 (8.1%)
Enzalutamide	2 (2.7%)
Apalutamide	1 (1.4%)

IQR = interquartile range. ADT = androgen deprivation therapy. Values are presented as median (IQR) for continuous variables and n (%) for categorical variables. Antiandrogen percentages reflect the proportion of the overall cohort (n = 74).

PSA Response to Treatment

Treatment produced significant, progressive PSA reductions at all follow-up time points (all $p < 0.001$; paired Wilcoxon signed-rank test).

At 3 months, the median absolute PSA change from baseline was -12.3 ng/mL (IQR: -21.9 to -3.5), corresponding to a median percent reduction of 91.9% (IQR: 40.9–99.3%); 73.2% of patients achieved a $\geq 50\%$ PSA reduction. At 6 months, the median PSA change was -13.2 ng/mL (IQR: -26.1 to -7.0), with a median percent reduction of 99.2% (IQR: 91.1–99.8%); 86.5% of patients achieved a $\geq 50\%$ PSA reduction. At 9 months, reductions deepened further, with a median PSA change of -17.2 ng/mL (IQR: -32.0 to

–8.2) and a median percent reduction of 99.7% (IQR: 97.0–99.9%); 93.0% of patients achieved a $\geq 50\%$ PSA reduction. The lowest recorded post-treatment PSA had a median of 0.028 ng/mL (IQR: 0.024–0.560). These findings are summarised in Table 3 and illustrated in Figure 1.

Table 3: PSA response from baseline at 3, 6, and 9 months

Characteristic	Median (IQR) or n (%)	p-value*
3 Months		<0.001
PSA Change (ng/mL)	–12.3 (–21.9 to –3.5)	
Percent Reduction (%)	91.9 (40.9–99.3)	
Patients with $\geq 50\%$ PSA Reduction	52 (73.2%)	
6 Months		<0.001
PSA Change (ng/mL)	–13.2 (–26.1 to –7.0)	
Percent Reduction (%)	99.2 (91.1–99.8)	
Patients with $\geq 50\%$ PSA Reduction	64 (86.5%)	
9 Months		<0.001
PSA Change (ng/mL)	–17.2 (–32.0 to –8.2)	
Percent Reduction (%)	99.7 (97.0–99.9)	
Patients with $\geq 50\%$ PSA Reduction	66 (93.0%)	
Lowest Post-treatment PSA (ng/mL)	0.028 (0.024–0.560)	

*IQR = interquartile range. *p-values are based on the paired Wilcoxon signed-rank test comparing PSA values at each time point with baseline.*

Clinical Outcomes

Disease recurrence occurred in 5.4% of patients (n = 4), with a median time to recurrence of 68.5 months (IQR: 47.9–92.2). Treatment-related morbidity included urinary incontinence, reported in 5.4% of patients (n = 4) at 3 months, 4.1% (n = 3) at 6 months, and 5.4% (n = 4) at 12 months, and erectile dysfunction, documented in 6.8% of patients (n = 5) at 12 months. Overall mortality was 6.8% (n = 5), with a median time to death of 66.8 months (IQR: 42.2–90.4); 80.0% of deaths were attributable to prostate cancer or its metastatic sequelae (Table 4).

Table 4: Clinical outcomes

Outcome	n (%) or Median (IQR)
Disease Recurrence	4 (5.4%)
Time to Recurrence (months)	68.5 (47.9–92.2)
Urinary Incontinence	
At 3 Months	4 (5.4%)
At 6 Months	3 (4.1%)
At 12 Months	4 (5.4%)
Erectile Dysfunction at 12 Months	5 (6.8%)
Death (all cause)	5 (6.8%)
Time to Death (months)	66.8 (42.2–90.4)
Cause of Death	
Prostate Cancer or Metastases	4 (80.0%)
Other Causes	1 (20.0%)

IQR = interquartile range. Values are presented as n (%) or median (IQR).

Factors Associated with Longitudinal PSA Levels

In the adjusted linear mixed-effects model, time since treatment initiation was independently associated with log-transformed PSA levels. Compared with baseline, statistically significant reductions in PSA were observed at 3 months ($\beta = -0.81$, 95% CI: -0.93 to -0.69 ; $p < 0.001$), 6 months ($\beta = -1.00$, 95% CI: -1.12 to -0.88 ; $p < 0.001$), and 9 months ($\beta = -1.13$, 95% CI: -1.25 to -1.00 ; $p < 0.001$). Metastatic status (M1 vs. M0) was associated with higher longitudinal PSA levels, whereas Gleason group and age at diagnosis were not statistically significant predictors. These results are illustrated in Figure 2.

Discussion

Primary Findings

In our single-institution series, combined androgen deprivation and radiotherapy produced deep and rapid biochemical responses. Within nine months of starting therapy, men in our cohort experienced a median PSA decline of 99.7%, reaching a nadir of 0.028 ng/mL — lower than the approximately 0.1 ng/mL typically reported in large registries. By three and six months, reductions were already 91.9% and 99.2%, respectively. Such early suppression suggests that moderate hypofractionated dosing with well-timed hormonal therapy can deliver biochemical control comparable to more intensive regimens.

Randomised trials support this premise. The GETUG 14 study showed that adding a four-month course of ADT to high-dose radiotherapy improved five-year disease-free survival from 76% to 84% and reduced biochemical failure and metastasis, though without a significant overall survival benefit [2]. RTOG 92-02 demonstrated that extending ADT beyond four months further reduces disease progression and biochemical recurrence; an overall survival advantage was confined to men with Gleason 8–10 disease [6]. RTOG 94-08 showed that short-course ADT increased 10-year overall survival from 57% to 62% and halved biochemical failure rates [1], while EORTC 22863 demonstrated that long-term ADT doubled disease-free survival without increasing cardiovascular mortality [3].

Not all trials report a survival advantage. Nabid et al. found similar survival whether radiotherapy was combined with six months of ADT or given alone, with benefit limited to unfavourable intermediate-risk subgroups [15], and National Cancer Data Base data suggest only men with multiple adverse features derive survival gains from ADT [16]. Nevertheless, two recent meta-analyses confirm that ADT meaningfully reduces biochemical failure: a 2025 review of over 6,000 participants reported a pooled survival hazard ratio of 0.88 and predicted an absolute survival gain of approximately 5% at ten years [7], and a 2022 meta-regression found that adding even short-course ADT to radiotherapy lowered prostate-cancer-specific mortality compared with radiotherapy alone [17].

Against this backdrop, our cohort's nadir of 0.028 ng/mL — well below the 0.1–0.2 ng/mL thresholds associated with long-term disease control in the literature [18,19] — supports the durability of short-course ADT combined with modern hypofractionated radiotherapy. Only 5.4% of men experienced biochemical recurrence, and the median time to recurrence approached six years. That said, the cohort is small, follow-up is modest, and PSA nadir remains a surrogate endpoint; long-term prospective data are needed to confirm whether deep early responses translate into sustained metastasis-free and overall survival benefits.

Response Kinetics

PSA kinetics in our cohort followed a consistent and early trajectory. By three months, 73.2% of patients had achieved a $\geq 50\%$ PSA decline; this proportion rose to 86.5% and 93.0% at six and nine months, respectively. These rates mirror population-level findings from the Stockholm PSA and Biopsy Register, where patients receiving combined RT and ADT reached deep PSA suppression within the first year, and delayed decline was associated with inferior prostate-cancer-specific outcomes [18]. Consistent with prior reports, patients who achieved lower nadirs demonstrated superior long-term biochemical control [19], and early PSA response has been shown to be strongly predictive of prostate-cancer-specific mortality [9] and biochemical relapse-free survival [8].

The rapid decline observed likely reflects the synergistic interaction between the two modalities: ADT suppresses androgen-driven tumour growth and enhances cellular radiosensitivity, while concurrent radiotherapy provides local disease control. Translational data support this mechanism, demonstrating that androgen receptor signalling regulates DNA damage repair, making tumour cells more susceptible to radiation after hormonal blockade [5].

Clinical Predictors

In our adjusted mixed-effects model, metastatic disease at presentation (M1) was associated with higher longitudinal PSA values after treatment. This is biologically plausible: metastatic disease reflects greater overall tumour burden, with bone being the most prevalent site in our cohort (13.5%), and such sites may respond variably to hormonal manipulation and radiation. Parker et al. (STAMPEDE) and Kyriakopoulos et al. (CHAARTED) have similarly demonstrated that metastatic burden negatively impacts biochemical outcomes and disease control despite intensive systemic therapy [20,21].

Contrary to expectation, neither Gleason grade nor high-risk classification significantly predicted PSA kinetics in our adjusted model, despite over half of patients having Gleason group 4–5 disease. This finding may partly reflect a treatment effect strong enough to attenuate histological differences – a hypothesis supported by trials demonstrating good biochemical control with combined modality therapy even in high-risk groups [3,6].

Safety and Treatment-Related Side Effects

The tolerability profile of our cohort was favourable. Urinary incontinence affected 5.4% of men at three months and 5.4% at twelve months, consistent with published rates following external-beam radiotherapy, where five-year actuarial incontinence rates of approximately 7% have been reported [12,23]. Erectile dysfunction was recorded in 6.8% of men at twelve months, a figure markedly lower than the 60–70% rates described after conventional external-beam radiotherapy in prospective series [10] and the 73–86% rates attributable to ADT alone [11].

This discrepancy warrants careful interpretation. Our retrospective chart review may underestimate sexual dysfunction, as erectile function was not systematically assessed at every visit. Additional explanations include the use of contemporary hypofractionated radiotherapy with careful sparing of the urethra and penile bulb, a short ADT duration, early phosphodiesterase-5 inhibitor use and lifestyle counselling, and a relatively brief follow-up period. Randomised evidence from the long-term update of NRG/RTOG 9408 confirms that adding short-term ADT does not substantially increase late genitourinary or gastrointestinal toxicity compared with radiotherapy alone [13]. Importantly, urinary incontinence may continue to develop years after radiotherapy [24], and sexual function often declines progressively during prolonged androgen deprivation [11]; continued monitoring of this cohort will therefore be essential.

Study Limitations

This study has several important limitations. The series comprised 74 patients from a single institution, limiting statistical power, generalisability, and the ability to detect uncommon adverse events. The retrospective design and absence of a control group introduce potential selection and information biases and preclude direct comparison with alternative treatment strategies.

Imaging represents a further limitation. Most patients were followed with conventional CT and bone scanning, which have limited sensitivity at low PSA levels [25]. PSMA PET/CT – now preferred by major

guidelines for staging high-risk disease and detecting biochemical recurrence — offers substantially higher accuracy (92% vs. 65%), sensitivity (85% vs. 38%), and specificity (98% vs. 91%) compared with conventional imaging, as demonstrated in the randomised proPSMA trial [26]. Because PSMA PET/CT was unavailable during most of the study period, small metastatic deposits may have been missed, potentially contributing to the low recurrence rate observed. Future studies employing PSMA PET/CT for surveillance will be needed to validate these findings and accurately quantify disease control in comparable populations.

Conclusion

In this cohort of 74 patients with predominantly high-risk prostate cancer treated with curative-intent radiotherapy combined with ADT, treatment was associated with rapid and sustained PSA suppression across all follow-up intervals. By 9 months, 93.0% of patients achieved a $\geq 50\%$ PSA reduction from baseline, and PSA levels continued to decline progressively over time. The linear mixed-effects model confirmed statistically significant PSA reductions at each time point relative to baseline, independent of age, Gleason group, and metastatic status. Treatment-related toxicity was low, with urinary incontinence and erectile dysfunction each occurring in fewer than 7% of patients at 12 months. The disease recurrence rate was 5.4%, with a median time to recurrence of 68.5 months. These findings support the efficacy and tolerability of combined radiotherapy plus ADT in this population and provide real-world PSA kinetic data that may complement randomised trial evidence.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of King Abdullah International Medical Research Center (KAIMRC), National Guard Health Affairs (Protocol No. NRR24/084/7). Given the retrospective design of the study and the use of routinely collected, de-identified clinical data, the requirement for individual informed consent was waived by the same Institutional Review Board.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to institutional data protection policies but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Not applicable.

Authors' contributions

Author initials used throughout this section: MAk, Mohammed Alkhamees; AN, Ahmed Nazer; AA, Ahmed Alaskar; ZA, Zeyad Alkhenaizan; WA, Waleed Alhejaili; MFA, Muhannad Alhabshan; MAt, Mohammed Alkatheeri; FA, Faris Altuwaim; TA, Talal Almushayt.

Dr. Mohammed Alkhamees (MAk), Dr. Ahmed Nazer (AN), and Dr. Ahmed Alaskar (AA) served as the supervising attending physicians for this study. All three provided overall clinical and academic oversight throughout the project, contributed to the conceptual framing and clinical interpretation of the findings, and critically revised successive drafts of the manuscript for important intellectual content. MAk, AN, and AA reviewed and approved the final version of the manuscript prior to submission and take responsibility for the integrity of the work as a whole.

Dr. Zeyad Alkhenaizan (ZA), Dr. Waleed Alhejaili (WA), Muhannad Alhabshan (MFA), Dr. Mohammed Alkatheeri (MAk), Dr. Faris Altuwaim (FA), and Dr. Talal Almushayt (TA) were involved in every stage of the study, from initial planning through to submission. Their contributions included obtaining institutional review board approval, designing the data collection protocol, extracting and collecting demographic, clinical, and treatment data from electronic medical records, performing the statistical analysis, interpreting the results, and drafting the original manuscript. All six authors reviewed subsequent revisions and approved the final version for submission.

All authors read and approved the final manuscript and agree to be accountable for all aspects of the work, including ensuring that questions related to the accuracy or integrity of any part of the study are appropriately investigated and resolved.

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Figures

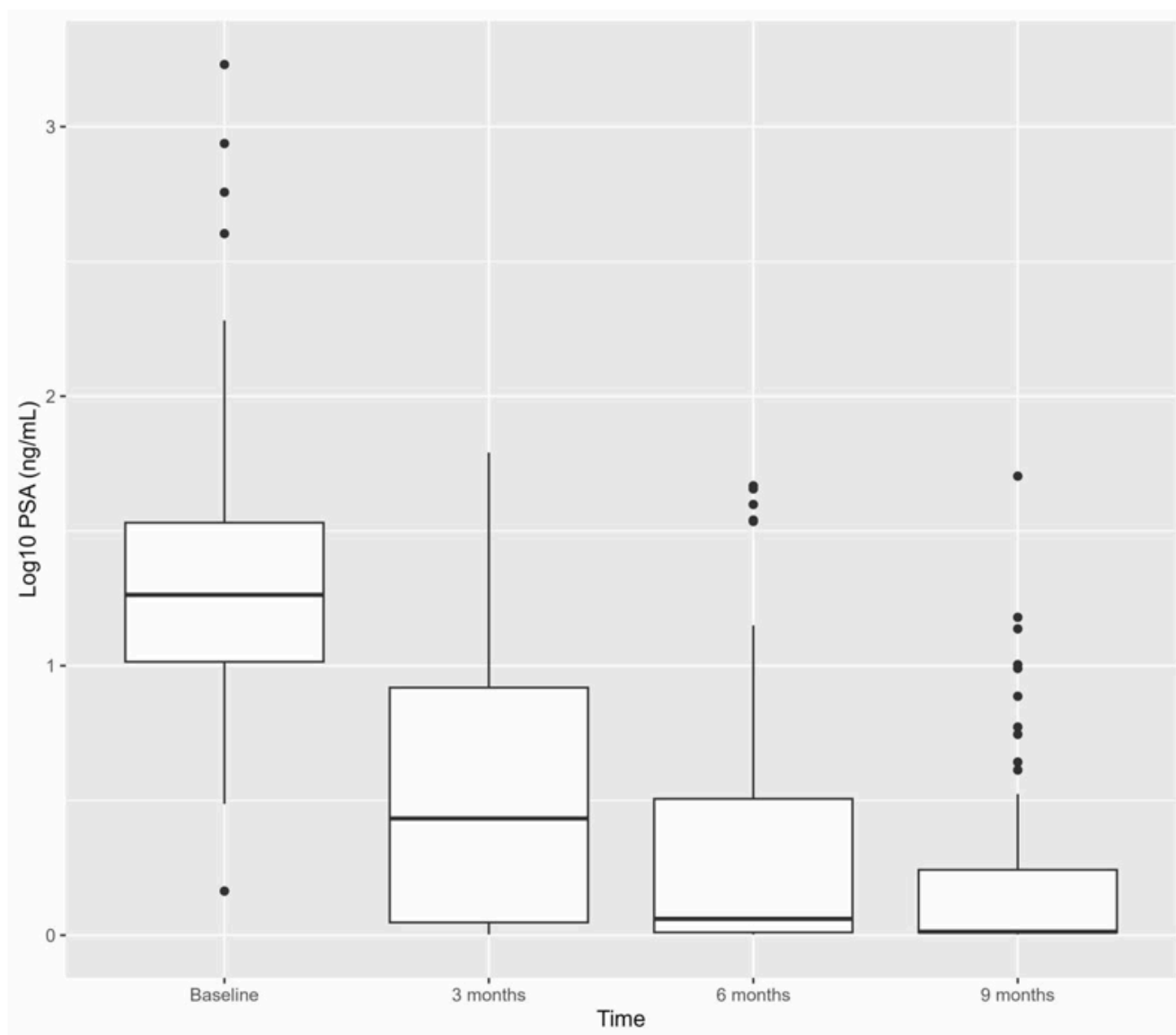


Figure 1

Boxplots depicting the changes in PSA at different time points. PSA values were $\log_{10}$ -transformed for graphical visualisation due to skewed distribution.

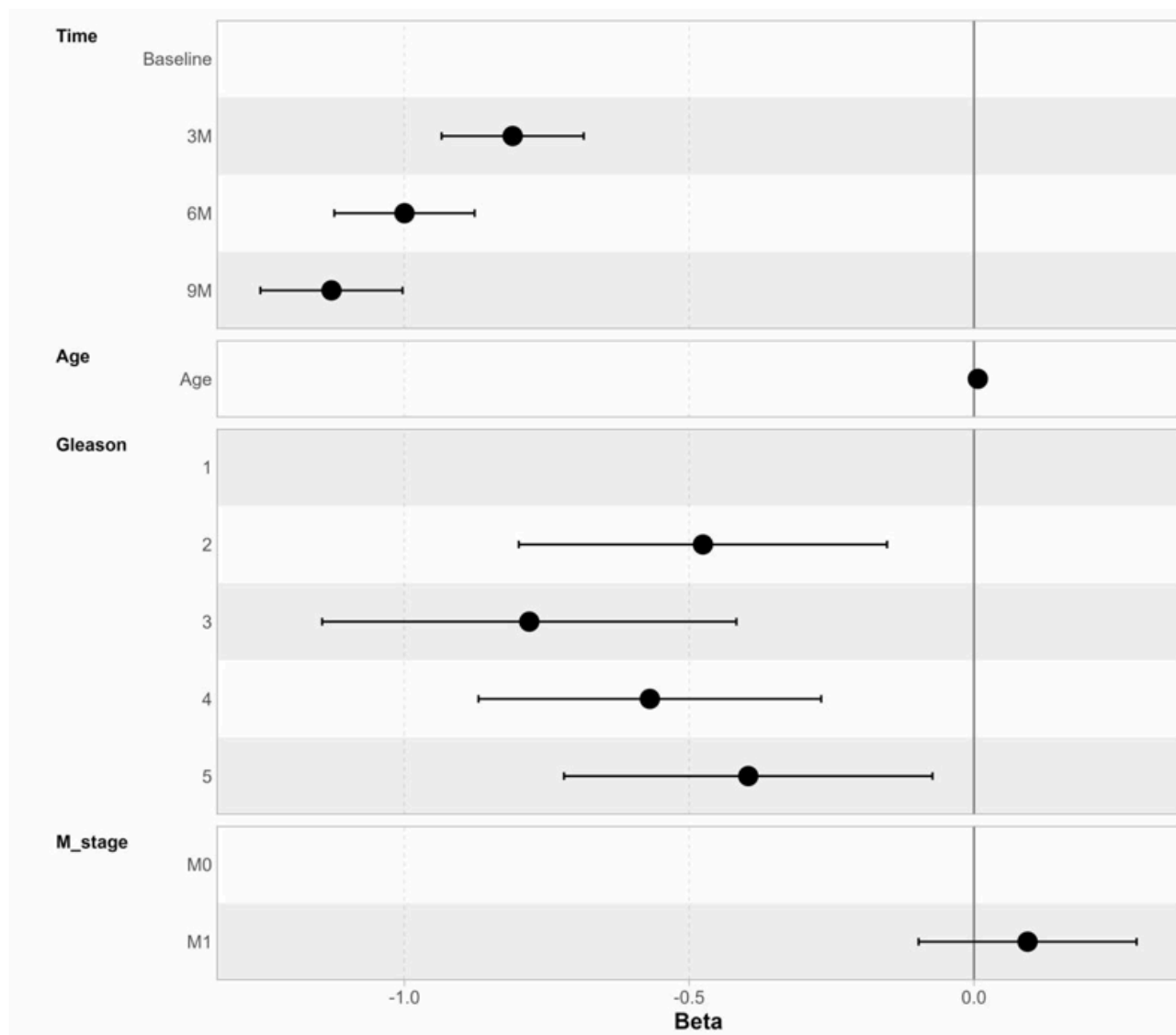


Figure 2

Forest plot of the adjusted linear mixed-effects model evaluating factors associated with longitudinal PSA levels following curative radiotherapy plus androgen deprivation therapy. The model included repeated PSA measurements at baseline, 3, 6, and 9 months (modelled as a categorical time variable) with a random intercept for each patient. Fixed effects included age at diagnosis, Gleason group, and metastatic status. PSA values were $\log_{10}$ -transformed ($\log_{10}[\text{PSA} + 1]$) prior to analysis. Points represent estimated regression coefficients and horizontal lines indicate 95% confidence intervals. Negative coefficients indicate a reduction in PSA relative to the reference category.