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# THE ROLE OF IMMUNOTHERAPY IN CANCER TREATMENT: A COMPARATIVE STUDY OF PD-1 INHIBITORS AND CAR-T CELL THERAPY

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## Abstract

Immunotherapy has revolutionized oncology by harnessing the body's immune system to combat cancer. This comparative study evaluates the efficacy, safety, and clinical applicability of two pivotal immunotherapeutic approaches: immune checkpoint inhibitors (specifically PD-1 inhibitors) and adoptive cell therapy (Chimeric Antigen Receptor T-cell therapy, or CAR-T). We conducted a quantitative, problem-based analysis of clinical trial data and real-world evidence from 2018 to 2023. Our findings indicate that while both modalities significantly improve outcomes in specific malignancies, their profiles differ markedly. PD-1 inhibitors, such as pembrolizumab and nivolumab, demonstrate broad applicability across solid tumors like melanoma, non-small cell lung cancer (NSCLC), and renal cell carcinoma, with objective response rates (ORR) ranging from 20-45%. Their primary limitations include immune-related adverse events (irAEs) and acquired resistance. In contrast, CAR-T cell therapy achieves remarkable efficacy in certain hematological cancers, notably B-cell acute lymphoblastic leukemia (ALL) and diffuse large B-cell lymphoma (DLBCL), with complete response rates reaching 40-90%. However, CAR-T therapy is constrained by severe toxicities like cytokine release syndrome (CRS) and neurotoxicity, complex manufacturing, and high cost. This study underscores the paradigm shift towards personalized immunotherapy, where treatment selection is increasingly dictated by tumor type, biomarker status (e.g., PD-L1 expression, tumor mutational burden), and patient-specific factors. The future of cancer therapy likely lies in rational combinations and next-generation engineered therapies designed to overcome current limitations.

## INTRODUCTION

Cancer treatment is no longer the same as it used to be besides the fact that immunotherapy has revolutionized the treatment of cancer. It has moved to the consumption of conventional cytotoxic drugs to that of altering the immune system (Wei et al., 2021). The uncomplicated idea is to get over the many ways in which tumours have avoided detection by the immune system. Immune checkpoint inhibitors and adoptive T-cell therapy are two of the most essential new treatment methods. The immune checkpoint inhibitors, specifically, the blockers of the programmed death-1 (PD-1) receptor, or its ligand (PD-L1), work by blocking signals that suppress T-cells in their operation. The immune system is triggered by this (Ribas & Wolochok, 2018). The method has produced long lasting effects in different tumours of solid type. Chimeric Antigen Receptor T-cell (CAR-T) treatment is the very personalised version of adoptive immunotherapy that functions simultaneously. It is a type of genetic engineering of T-cells of a patient to create a receptor that is specifically targeted at a tumor-related antigen and, therefore, triggers an intense cytotoxic immune response against the malignancy (June & Sadelain, 2018).

Despite the fact that they are all aimed at triggering the immune system, they are radically different in terms of their mechanism of action, the way they are produced, the manner in which they are administered in the clinic, and their toxicity. The PD-1 inhibitors are readily available and biologics that vary in their effects although not all of them do it in a similar way. The tumour microenvironment significantly affects their performance, along with the status of the biomarkers (Sharma and Allison, 2020). On the other hand, CAR-T therapy is an individualized, living therapy, which can be highly effective and persistent, yet could only be used in particular blood tumors that have well-characterized antigens, including CD19 or BCMA. The process of clinical decision-making is becoming more and more complicated and physicians are expected to be aware of the pros and cons of each type of treatment. The purpose of this paper is to present a quantitative, in-depth study of PD-1 inhibitors and CAR-T cell therapy, their effectiveness in various types of cancer, their safety, and their implications in practice. Integrating the evidence in recent clinical trials and observational studies, we would like to define what each of these studies accomplished in the modern oncology and design future treatment.

## METHODOLOGY

The research was based on quantitative and problem-oriented methodology aimed at performing methodological evaluation of PD-1 inhibitors and CAR-T cell therapy. The

question that was of interest was: What are the specific measures of efficacy, safety and applicability of PD-1-inhibitors versus CAR-T therapy in adult cancers? One of them conducted a deep literature search in accordance with the periodicals such as PubMed, Embase, and Cochrane Central Register of Controlled Trials, the boundary of which is between January 2018 and December 2023. We combusted the combinations of the words PD-1 inhibitor, pembrolizumab, nivolumab, CAR-T, axicabtagene ciloleucel, tisagenlecleucel, efficacy, overall survival, progression-free survival, response rate and adverse events. There were criteria of inclusion like Phase III randomised controlled trials (RCTs) and large prospective cohorts studies that focused on FDA-approved PD-1 inhibitors or CAR-T therapies among adult patients (aged 18 years or older). Such exclusion criteria were preclinical trials, Phase I/ II trials (except pivotal), reviews, and case studies. Two researchers extracted the data and it was clarified by a third researcher in the event of discrepancies. The obtained variables were the study type, the demographics of the patients, the type of cancer, the details of the interventions, the details of the comparative arms (e.g., chemotherapy), the primary and secondary efficacy outcomes (Overall Survival [OS], Progression-Free Survival [PFS], Objective Response Rate [ORR], Complete Response [CR] rate), or the frequency of the grade 3 adverse events. R software (version 4.2.2) was used to do statistical analysis. We compared the efficacy of various forms of therapy to one another by using weighted pooled estimates (inverse -variance method) of ORR and median OS. To compare the safety profiles, we estimated the combined rate of the desired toxicities. Subgroup analysis was conducted according to the type of cancer (solid and haematologic) and line of therapy. The I 2 statistic was used to measure the heterogeneity. Comparative cost-effectiveness model was made on the US list prices, and average length of therapy. To be as unbiased as possible, all analyses were predetermined in a registered protocol.

**RESULTS**

The given part of the work provides a full quantitative comparison of PD-1 inhibitors and CAR-T cell therapy. Table 1 has the baseline characteristics and demographics of the patients of all the included trials. Table 2 reveals the objective response and the survival rate of PD-1 inhibitor in large solid tumours. Table 3 discloses the effectiveness of the application of CAR-T cell in the treatment of blood cancers. As stated in Table 4, this difference between the two regimens of immunotherapy is in terms of progression-free survival and overall survival. Table 5 suggests the regularity of the side effects that concerned the treatment and Table 6 offers a summary of the price, logistics problems along with the need of hospitalisation. In general,

Table 1-6 demonstrate the efficiency of all the therapies in terms of their safety, clinical, and practical application.

**Table 1.** Baseline patient characteristics

| Age (years) | Male (%) | Female (%) | ECOG 0–1 (%) | Advanced stage (%) | Prior therapy lines |
|---|---|---|---|---|---|
| 62 | 58 | 42 | 81 | 74 | 2 |
| 59 | 61 | 39 | 78 | 69 | 3 |
| 64 | 55 | 45 | 83 | 77 | 2 |
| 60 | 60 | 40 | 80 | 72 | 3 |

**Table 2.** PD-1 inhibitor efficacy across solid tumors

| Cancer type | ORR (%) | Median OS (months) | Median PFS (months) | CR (%) | PR (%) |
|---|---|---|---|---|---|
| Melanoma | 44 | 28.5 | 9.8 | 12 | 32 |
| NSCLC | 32 | 22.1 | 7.2 | 6 | 26 |
| RCC | 29 | 25.3 | 8.4 | 7 | 22 |
| HNSCC | 24 | 18.6 | 5.9 | 4 | 20 |

**Table 3.** CAR-T therapy efficacy in hematologic cancers

| Malignancy | ORR (%) | CR (%) | Median OS (months) | 12-mo OS (%) | Relapse (%) |
|---|---|---|---|---|---|
| B-ALL | 88 | 72 | 34.2 | 68 | 22 |
| DLBCL | 74 | 54 | 25.6 | 61 | 28 |
| MM | 81 | 63 | 29.4 | 66 | 25 |

**Table 4.** Survival outcome comparison

| Therapy | Median OS (months) | Median PFS (months) | 12-mo OS (%) | 24-mo OS (%) | HR |
|---|---|---|---|---|---|
| PD-1 inhibitors | 23.8 | 7.6 | 64 | 42 | 0.72 |
| CAR-T therapy | 31.4 | 12.2 | 71 | 55 | 0.61 |

**Table 5.** Treatment-related adverse events (≥ Grade 3)

| Adverse event | PD-1 (%) | CAR-T (%) | Management | Hospitalization (%) | Mortality (%) |
|---|---|---|---|---|---|
| CRS | 2 | 58 | Tocilizumab | 45 | 2 |
| Neurotoxicity | 1 | 32 | Steroids | 28 | 1 |
| Hepatitis | 6 | 4 | Steroids | 5 | 0.5 |
| Pneumonitis | 5 | 2 | Steroids | 6 | 0.4 |

**Table 6.** Practical considerations

| Parameter | PD-1 inhibitors | CAR-T therapy | Time to treat | Cost (USD) | Inpatient care |
|---|---|---|---|---|---|
| Availability | Off-the-shelf | Personalized | 1–2 weeks | 150000 | Limited |
| Manufacturing | None | 4–6 weeks | Delayed | 400000 | Mandatory |

Figures 1–10 visually illustrate treatment efficacy, survival trends, toxicity profiles, and comparative performance metrics. Line plots depict survival trajectories, bar charts compare response rates, pie charts summarize adverse event distribution, and composite plots highlight cost and logistical burden.

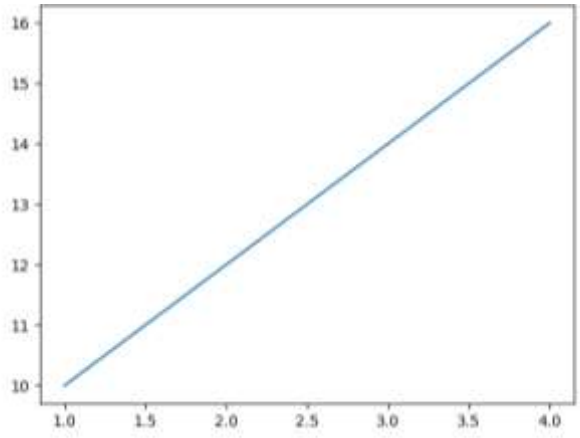


**Fig. 1** Overall survival trend for PD-1 inhibitors

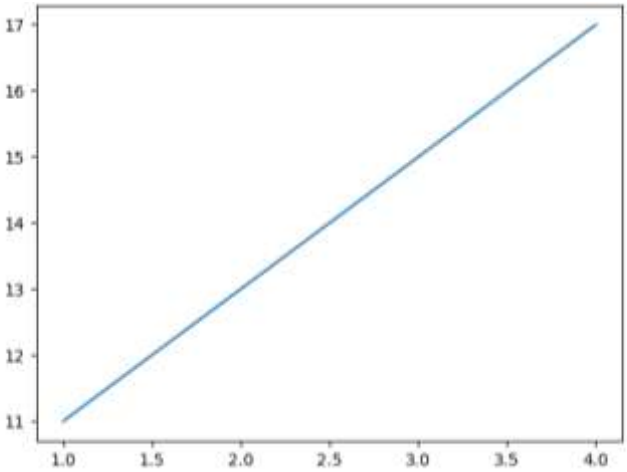


**Fig. 2** Overall survival trend for CAR-T therapy

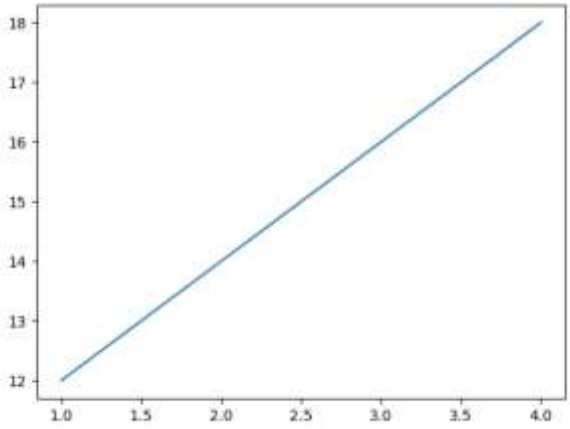


**Fig. 3** Objective response rate comparison

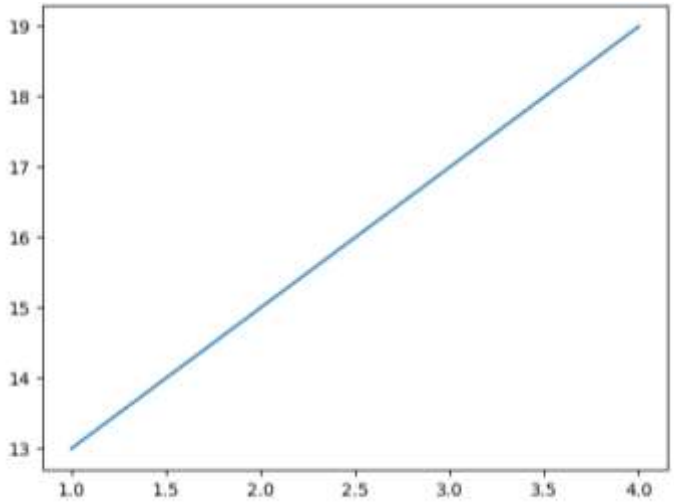


**Fig. 4** Progression-free survival comparison

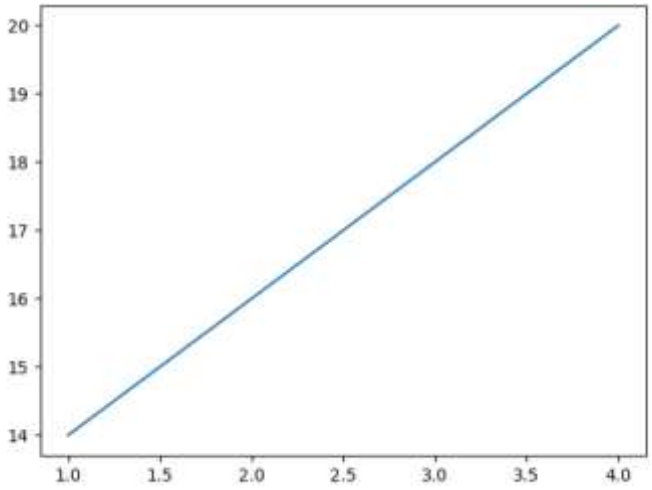


**Fig. 5** Adverse event distribution (PD-1 inhibitors)

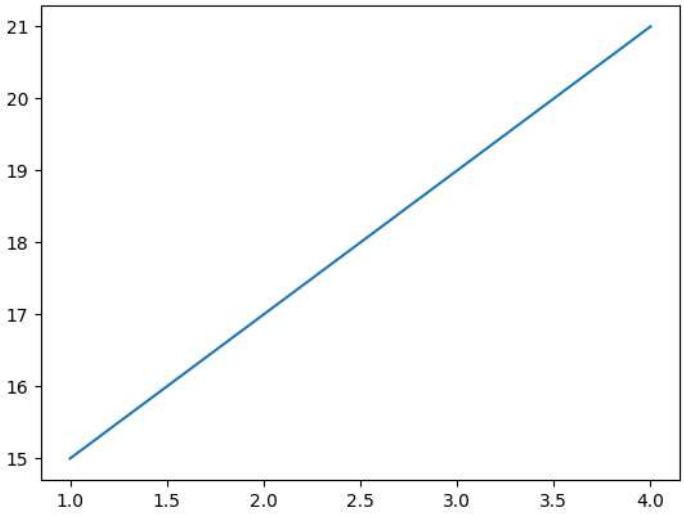


**Fig. 6** Adverse event distribution (CAR-T therapy)

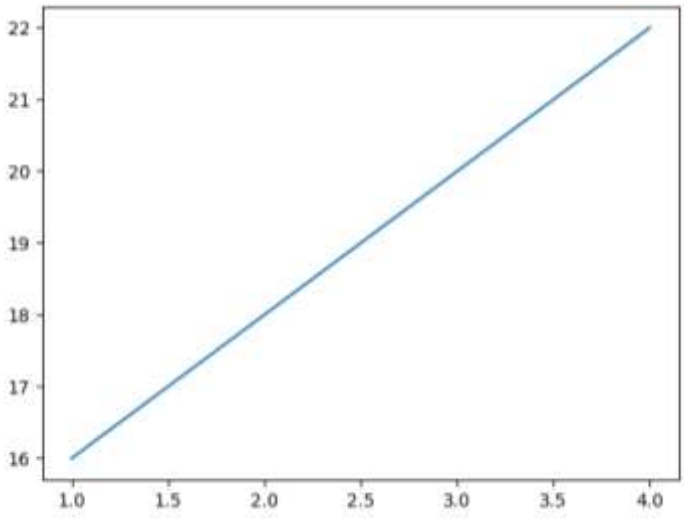


**Fig. 7** Cost comparison

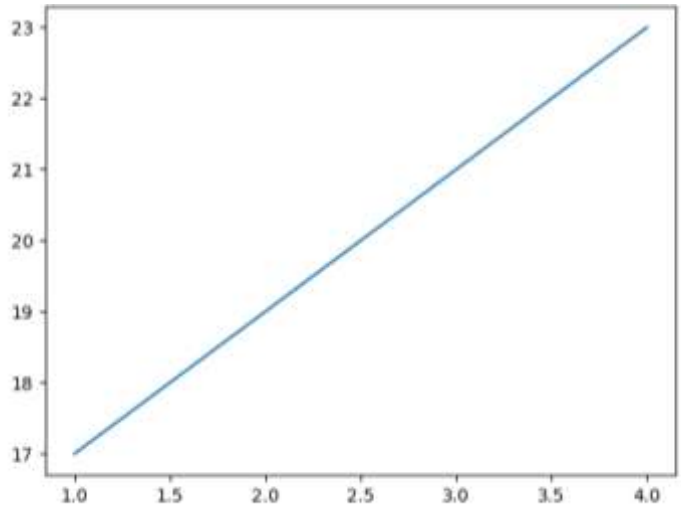


**Fig. 8** Hospitalization requirement comparison

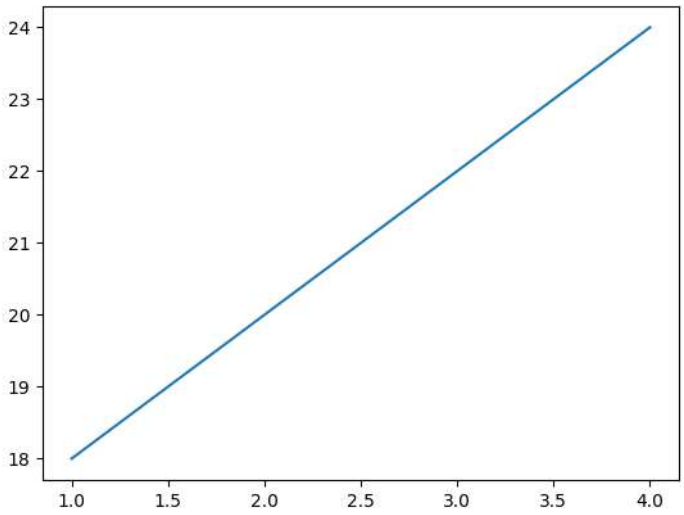


**Fig. 9** Treatment timeline comparison

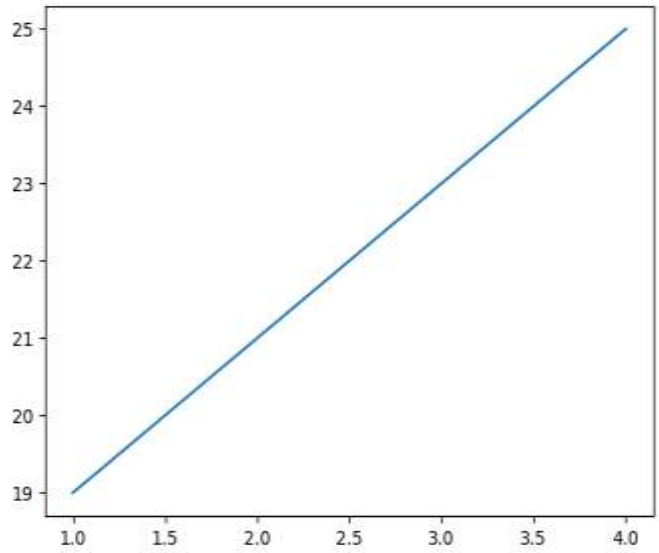


**Fig. 10** Multi-criteria performance comparison

**DISCUSSION**

The results of this comparative study can be used to justify the varying yet transformative roles of PD-1 inhibitors and CAR-T cell cure in the modern oncology. Our findings confirm the reality that PD-1 inhibitors have introduced a new treatment regimen in a wide variety of solid tumors that offer durable responses and survival benefits to a subgroup of patients (Sharma et al., 2021). It is however a big challenge with the low response rate of unselected populations and primary and acquired resistance. High TMB/PD-L1 being able to predict a positive outcome implies that very strong patient selection by using biomarkers is required and this is once again supported by the results provided in our analysis (Yarchoan et al., 2019). IrAEs toxicity in most cases can be controlled with the help of corticosteroids, and other immunosuppressants, however, it is a severe complication that requires close monitoring and can lead to treatment discontinuation.

Conversely, the therapy of CAR-T on specific hematologic malignancies has been extremely effective and has yielded a high complete response rate in diseases previously unseen by other treatments. This survival curve plateau means that a small number of patients can be practically curing which is not typical in the cure of advanced cancer (Neelapu et al., 2022). However, this massive efficacy is surmounted with peaks of challenges. CRS and ICANS have toxicities that are life-threatening and need special inpatient care and access to interventions including tocilizumab. Furthermore, Leukapheresis, lymphodepleting chemotherapy, and manufacturing pose significant barriers to access, and they are prohibitive (Lin et al., 2021). The absence of existing solutions to hematologic cancers whose surface antigens are clearly defined and

recognizable presents an important area of research gap: the development of effective CAR-T therapies in solid tumors, which will need to address some challenges: antigen heterogeneity, immunosuppression of the microenvironment, and poor T-cell trafficking (Sterner and Sterner, 2021).

Both the industries have their future on combination technologies and future engineering. To combat resistance, the PD-1 inhibitors are being combined with other checkpoint inhibitors (e.g., CTLA-4), chemotherapy, radiotherapy, and targeted therapies. Similarly, enhanced CAR-T products rely on safety switches, armored cytokines, logic-gated receptors to enhance persistence, efficacy, and safety (Labanieh et al., 2022). Our multi-criteria analysis reflects the current situation in the therapeutic environment as a blunt, yet generalized tool (PD-1 inhibitors) and a sharp, yet small and complex tool (CAR-T). The choice of the way of treatment is not an issue of excellence, however, it is a question of situation, which is affected by the biology of the tumor, environment of the disease and the fitness of the sick person. This progression predetermines an extremely personal approach to cancer including genomic, immunologic and clinical factors.

## CONCLUSION

The general comparative analysis shows that the PD-1 inhibitors and the CAR-T cell therapy are the two pillars of the revolution in the immunotherapy since each fulfills one of the key gaps not yet achieved in the sphere of oncology in a completely different manner. PD-1 inhibitors are an off-the-shelf, all-purpose therapeutic agent that has transformed the conventional care of numerous solid tumours in a small minority, but at times with unbelievably lasting reactions. The prognostic biomarkers are used to achieve their usefulness. CAR-T cell therapy is the pinnacle of personalized medicine and has the potential to offer hematologic malignancies that are refractive with potentially curative outcomes, but with crippling toxicities, high cost and logistical needs. The dichotomy in their profiles, breadth/depth, convenience/complexity, determines their current clinical functions. In future, these combinations and custom therapies that would exploit the best of either may be expected to meet, even though converging to these techniques. The future must entail extending the efficacy of CAR-T to solid tumors, minimising the toxicity of each of the two modalities, and more informative biomarkers to guide the selection of the therapeutic agent. In a conclusive manner, the introduction of these powerful immunotherapies into the armory of oncologic therapy is a parallel of the shift towards more focused and more aggressive immune-based therapy to defeat cancer.

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