Cancer Therapy: Clinical

Individual Patient-Specific Immunity against High-Grade Glioma after Vaccination with Autologous Tumor Derived Peptides Bound to the 96 KD Chaperone Protein

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Abstract

**Purpose:** Cancer immunotherapy offers hope of a highly specific nontoxic adjuvant treatment. Heat shock protein peptide complexes (HSPPCs) found in cancer cells carry tumor-specific antigenic proteins and can facilitate adaptive and innate immune responses. Here we show that peptides bound to a 96 kD chaperone protein (HSP-96) from brain tissue containing glioblastoma multiforme (GBM) can be used to safely immunize patients with recurrent GBM.

**Experimental Design:** Multimodality immunomonitoring was completed on 12 patients with recurrent GBM before and after immunization with an autologous HSPPC vaccine derived from surgically resected tumor. Clinical endpoints included safety assessments and overall survival.

**Results:** No adverse events attributable to the vaccine were found. Testing of peripheral blood leukocytes before and after vaccination revealed a significant peripheral immune response specific for the peptides bound to HSP-96, in 11 of the 12 patients treated. Brain biopsies of immune responders after vaccination revealed focal CD4, CD8, and CD56 IFNγ positive cell infiltrates, consistent with tumor site specific immune responses. Immune responders had a median survival of 47 weeks after surgery and vaccination, compared with 16 weeks for the single nonresponder.

**Conclusions:** These data provide the first evidence in humans of individual patient-specific immune responses against autologous tumor derived peptides bound to HSP-96. Clin Cancer Res; 19(1); 205–14. ©2012 AACR.

Introduction

Primary malignant brain tumors are uniformly fatal, and the 5-year survival rate for the highest grade of malignant glial neoplasm, glioblastoma multiforme (GBM), is now less than 4% (1). Improvements in conventional treatment modalities have provided some progress; however median survival remains at just over 1 year from initial diagnosis for patients treated at tertiary care centers (2). Survival data reported for GBM patients from the National Cancer Institute Surveillance Epidemiology and End Results Cancer are significantly worse, possibly reflecting discordance between community based and tertiary practice patterns (3). Currently approved therapy for a newly diagnosed GBM patient in the United States includes maximal surgical resection followed by radiation and temozolomide (1). Upon recurrence there are few approved options and these include surgical implantation of chemotherapy bearing wafers (ref. 4; polifeprosan 20 with carmustine implant, Gliadel Wafer) and systemic administration of the anti-angiogenic agent bevacizumab (Avastin; refs. 5, 6). Each of these therapies has shown modest improvement in survival of recurrent GBM patients, with notable treatment related toxicities including wound breakdown after surgical resection (7). Bevacizumab as a single agent in particular may be problematic for recurrent GBM patients because progression patterns after treatment can be multifocal, which is atypical for glioma recurrence (8).

There is an unmet medical need for highly specific and nontoxic adjuvant therapy to treat recurrent GBM patients undergoing surgical resection. Off target effects of adjuvant therapy for brain tumor patients can be particularly disabling, including focal neurologic deficits and cognitive dysfunction (9). Immunotherapy is an appealing method to specifically target tumor cells in glioma patients because of the potential to minimize adverse treatment effects (10). Several methods have been used successfully to evoke antitumor immunity in GBM patients, with evidence of peripheral and site-specific immune responses (11–15).
Heat shock protein (HSP) peptide complex (HSPPC-96) consists of the HSP gp96 and a wide array of chaperoned proteins, including antigenic peptides. HSPPC-96 immunization works mechanistically by interacting with antigen presenting cell (APC) via specific receptors, including CD91 (16, 17). After binding to CD91, the HSPPC-96 complex is internalized and the chaperoned peptides are presented by Class I and Class II Major Histocompatibility Complexes. The highly specific nature of the interaction between HSPPC-96 and APCs is a significant advantage over other cancer vaccine approaches; and has been shown to facilitate robust CD4⁺ and CD8⁺ T-cell immune responses (18, 19). Clinical grade HSPPC-96 can be easily purified from solid tumor and has been safely tested in hundreds of patients with a variety of solid tumor types (20–23).

Materials and Methods

Patient population

All 12 patients treated with vaccine were enrolled at the University of California, San Francisco. Presurgery eligibility included the presence of resectable recurrent glioma tumor tissue of grade 3 or 4. Patients with a Karnofsky Performance Status of ≥60 and a life expectancy greater than 8 weeks were eligible for the study. All eligible patients with ≥4 vaccines available for clinical use received investigational therapy. All patients enrolled (N = 28) were surgical candidates based on presumed radiographic progression of intracranial tumor who were not being treated with corticosteroids at the time of surgical resection. Intraoperative tissue was confirmed to be recurrent glioma prior to sending for vaccine manufacturing at Agenus Incorporated. Patients underwent biopsy after vaccine administration as part of standard care, and not exclusively for the purposes of this study. Patients who underwent biopsy after vaccine administration were consented for surgery in the standard fashion. The clinical trial is registered at www.clinicaltrials.gov (NCI0293423).

Exclusion criteria

Presurgery exclusion criteria included a history of immunodeficiency or immunosuppressive drug use excluding corticosteroids, current malignancies at other sites or other cancers within 5 years, active uncontrolled infection, and other serious medical conditions. Between 2 and 4 weeks after surgery, patients were evaluated to confirm eligibility, which included the availability of 7 g of viable tumor tissue from which to generate vaccine. The first cohort of 6 patients received 25 micrograms of HSPPC-96 every 2 weeks for the first 4 vaccinations followed by 2 week dosing. The second cohort of 6 patients received 25 micrograms of HSPPC-96 every week for the first 4 vaccinations followed by 2 week dosing. The trial was approved by the University of California, San Francisco Institutional review board and was done in accordance with the Declaration of Helsinki and guidelines for Good Clinical Practice.

During treatment, patients were evaluated for safety, toxicity, autoimmunity, and injection site reactions. Patients underwent tumor assessments clinically every 4 weeks and radiographically every 8 weeks per standard of care protocol. Immune response was evaluated at time points obtained prior to surgery, baseline (prior to the first treatment), and a posttreatment time point. The primary endpoint was safety and feasibility. Secondary endpoints were overall survival and immune response to therapy (treatment 1 blood sample compared with later vaccination time points).

Radiographic assessments

Standard MRI scans with contrast were obtained at 8-week intervals on each patient or at shorter intervals if clinically indicated (i.e., new neurologic deficit or deterioration). Patients with evidence of a moderate increase in contrast enhancement after vaccination (i.e., up to 20% increase in any residual enhancement after surgical resection) were not declared as tumor progressions unless there was an associated clinical decline. As indicated above, if medically indicated patients underwent biopsy or surgical resection after treatment with vaccine.

Vaccine preparation

Macroscopically non-necrotic tumor was surgically resected and shipped on dry ice to Agenus Incorporated and processed under current good manufacturing practice conditions. HSPPC-96 preparations were dispensed into individually identified, 25-μg aliquots, and shipped on dry ice to the pharmacy, where they were stored at −80°C.

Peripheral blood leukocyte isolation

Approximately 90 mL of blood was obtained prior to surgery, baseline (before the first treatment), and a
posttreatment time point, stored at room temperature, and processed within 2 hours of the blood draw for the isolation of peripheral blood leukocytes (PBL). PBLs were isolated by Ficoll centrifugation and stored in liquid nitrogen until the time of analysis.

**Tumor infiltrating leukocyte isolation**

Tumors were Collagenase D treated for 45 minutes at 37°C and mechanically dissociated. Tumor-infiltrating lymphocytes (TIL) were isolated with a 3-step Percoll density gradient as described (24).

**In vitro restimulation**

Restimulations of bulk PBL were done using 10 μg/mL of autologous vaccine (agp96) remaining in the UCSF pharmacy following patient removal from the trial. If all vaccine was used, retain vaccine was obtained from Agenus, Inc. Ten micrograms per milliliter recombinant human gp96 TRA-1 (rgp96, AbNova, Inc.) was used as a negative control. Cells were stimulated for 48 hours for quantitative PCR (qPCR) analysis, or 72 hours for intracellular cytokine staining or proliferation. All assays were done in triplicate. Negative controls included isotype control staining for each antibody, unstimulated cells from all time points and rgp96 stimulated cells for all time points. In some cases, due to limited supply of the residual vaccine, restimulation assays were not done.

**Intracellular cytokine staining**

Positive controls were single color staining for CD45 in each channel and phorbol 12-myristate 13-acetate (PMA)/Ionomycin (Sigma) stimulation to induce IFNγ production. Intracellular cytokine staining (ICS) was used to examine T-cell (defined as CD3 positive, CD4 or CD8 positive), and natural killer (NK) cell (defined as CD3 negative, CD56, or NKGD2D positive) IFNγ production following restimulation. Regulatory T-cell percentages were also examined (defined as CD3 positive, CD4 positive, CD25 positive, and FoxP3 positive). Fluorescently conjugated antibodies were acquired from Becton Dickinson or eBioscience. Gates were set based on the population of interest relative to positive and negative controls. Positive cells were determined to be those above the threshold fluorescence intensity based on negative controls listed above for each patient.

**Reverse transcription and qPCR**

Cells were stimulated as described above for 48 hours and whole cell mRNA was isolated using the Qiagen RNeasy MicroKit (Qiagen Inc). A total of 250 ng mRNA was reverse transcribed using Superscript III First Strand Synthesis System (Invitrogen). cDNA was amplified using target specific primers and the Sybr Green Master Mix (Applied Biosystems) and analyzed using a BioRad q5 thermocycler (Bio-Rad). The primer sets used were hypoxanthine phosphoribosyltransferase (HPRT) forward 5′ GAC CAG TCA ACA GGG GAC AT 3′, HPRT reverse 5′ GAT GAC TTC GAA AAG CTG 3′, IFNγ reverse 5′ ATA TTG CAG GCA GGA CAA CC3′. All qPCR samples were first analyzed using the Livak method and expressed as mRNA units relative to the housekeeping gene HPRT, which was selected because it is present in low copy number and varies minimally following stimulation. All expression levels were displayed as relative to the level expressed by the presurgery unstimulated PBL for each patient using the Pfaffl method.

**Proliferation**

PBLs were enriched for T cells by negative magnetic selection using Easy Sep CD3 enrichment kit according to the manufacturer’s instructions (Stem Cell Technologies Inc.). Proliferation was assessed in T cells by carboxyfluorescein succinimidyl ester (CFSE) dilution detected by flow cytometry using the CellTrace CFSE Cell Proliferation kit (Invitrogen) according to manufacturer’s instructions. Enriched T cells were incubated with 10 micromolar CFSE for 10 minutes, quenched with 5 volumes of complete media and washed 3 times. CFSE stained cells were then subjected to in vitro restimulation described above for 72 hours, and analyzed by flow cytometry for CFSE dilution.

**Peripheral blood leukocytes phenotyping**

Phenotypes of circulating cells were assessed prior to surgery, prior to administration one, and just prior to administration 3. Cells were stained for 25 minutes on ice with the following antibody combinations and washed 3 times: (i) CD3 FITC, CD8 PE, CD4 PerCP, NKGD2D APC, (ii) FoxP3 FITC, CD4 PE, CD3 PerCP, FoxP3, and CD25 APC, and (iii) CD3 FITC, CD8 PE, CD56 PeCy7, NKGD2D APC. All antibodies for surface staining were obtained from BD Pharmingen or eBioscience. PBLs were then analyzed for protein expression by flow cytometry.

**Flow cytometry**

Samples were stained with antibody cocktails as described above and analyzed using a BD FACSCalibur. Samples were acquired using CellQuest Pro software and analyzed using FlowJo software (Treestar).

**Statistical analysis**

Comparison of samples to determine statistical significance was conducted using a students’ 2-tailed t test. Statistical significance was determined by Prism graphing software with a P value <0.05 required to be statistically significant (Graphpad Inc). In patients lacking sufficient residual vaccine for restimulation across all assays, restimulation was analyzed with the assay using the least amount of patient vaccine, qPCR. The positive response was based on the statistically significant induction of HSPPC-96 response over background. Determination of patient overall responsiveness to vaccine was based on qPCR data as no patient who was analyzed for all assays was positive for qPCR and negative for flow cytometry.
Results

To assess the feasibility, safety, and antitumor immunogenicity of HSPPC-96 in patients with recurrent high-grade glioma we initiated a Phase I dose escalation trial. Twelve patients met inclusion criteria for postsurgical enrollment and safety assessments. The mean age of the treated patient population was 52 years (range: 36 to 73 years), and patients were treated with a variety of adjuvant therapies prior to recurrence (patient demographics are shown in Supplementary Tables S1A–S1C). In terms of feasibility, 28 patients were enrolled initially but only 12 met the final inclusion criteria for treatment and safety assessments. Reasons for exclusion from analysis included the following: processing error during surgical resection (1 patient), resected tumor was predominantly treatment effect with minimal viable tumor for vaccine and therefore inadequate for vaccine production (9 patients), consent was withdrawn after sending tumor for production but prior to vaccination (5 patients), clinical deterioration or progression prior to administering 4 vaccines with requisite follow-up (2 patients).

Consistent with previous reports (23, 25), no toxicity attributable to HSPPC-96 was observed in any of the 12 patients treated, with the exception of mild injection site erythema and/or induration (<5 mm). There were no serious adverse events associated with vaccine administration (Supplementary Table S2). To document peripheral immune responses we developed a novel assay that takes advantage of HSP’s unique specificity for binding of APCs. Pre- and postvaccine blood from all patients was evaluated by an antigen representation assay using autologous HSPPC-96 (agp96) in parallel with recombinant (nonantigen bearing) HSP-96 (rgp96), as a control for nonspecific responses attributable to HSP-96. IFNγ production was then measured using qPCR. Further analysis was conducted on a subset of patients including: (i) ICS to detect which immune effector cells were secreting proinflammatory cytokines, (ii) CFSE dilution to assay T-cell proliferation in response to tumor specific antigen, and (iii) phenotyping of PBL surface markers to characterize the peripheral immune compartment. When feasible, postvaccination, site directed brain tumor biopsies were conducted, with analysis of infiltrating immune effector cells. A summary of the assays and description of implementation for each patient with specific time points are shown in Supplementary Fig. 2A–C and Table 1.

Eleven of the 12 patients had a significant response to HSPPC-96 when controlling for the nonspecific adjuvant effect of HSP; indicating specific immunization against chaperoned antigenic peptides. An example of an immune responder compared with the single nonresponder is shown in Fig. 1A. Patient #009 experienced a 14.1-fold increase in IFNγ transcription by total PBLs in response to antigenic gp96

### Table 1. Summary of patient study #, assays conducted, immune monitoring time point, and overall survival after tumor resection

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<th>CFSE</th>
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**NOTE:** Ex vivo restimulation assays were conducted to determine specific immune responses to HSPPC-96. The time points for each patient included (A) presurgery, (B) postsurgery and prevaccination, and (C) at the time of the final vaccination. Restimulation was conducted using 10 μg/mL HSPPC-96 or recombinant gp96 for 48 hours. Statistical significance of responses was determined by comparing cytokine production (i) relative to prestimulation with HSPPC-96 and (ii) relative to recombinant gp96 protein (tumor peptide negative). Patients responses were evaluated as * if $P < 0.05$ for both for a given assay using a 2-tailed Student t test. All patients in the Phase I/II cohort were analyzed by whole cell reverse transcription and qPCR for IFNγ production following restimulation. When sufficient residual vaccine was available, additional assays were conducted, including intracellular cytokine staining and analysis of proliferation using CFSE dilution. Patients were classified as overall responders if they were * for at least 1 assay. ND, not determined due to lack of residual vaccine.
(agg96) following vaccination as compared with patient #003 who had only a 3.28-fold increase, which was not significant when compared with the effect of recombinant gp96 (rgp96). Figure 1C shows that 11 of 12 patients had a significant increase in IFN-γ production following restimulation. To identify the populations of immune effector cells responsible for the observed increase in IFN-γ production, we had conducted flow cytometry based ICS. Following restimulation with agg96, we found that innate NK cells and adaptive T cells contribute to the IFN-γ production observed by qPCR (Fig. 2A–C). An increase in IFN-γ producing T cells suggests that peptides chaperoned by gp96 induced peptide specific T-cell expansion following repeated vaccination. Because of reagent limitations (i.e., not all patients had sufficient vaccine for both clinical use and immunomonitoring), exploratory assays including ICS, CFSE and phenotypic analysis could only be conducted on a subset of patients. IFN-γ production was associated with T-cell proliferation in response to agg96 restimulation. An example of this is shown in Fig. 3, with 12.4% of T cells proliferating...
following vaccination and restimulation in patient #007 after 19 vaccinations. The data for patient #007 indicate that T-cell division is driven by agp96, consistent with tumor peptide specific responses. This is in contrast to the data from the nonresponder patient #003, with only 1.1% of T cells proliferating in response to restimulation with agp96.

In patients who underwent surgery after vaccination, a postvaccine biopsy at the original tumor site was conducted. An increase in IFNγ positive CD3⁺, CD8⁺, and CD3⁺, CD8⁺ cells (Fig. 4), and CD3⁻, CD56⁺ cells (Fig. 5), was seen in all patients biopsied, indicating localization of immune effector cells to the tumor site after vaccination. Phenotypic analysis of circulating T cells shown in Supplementary Fig. 2 provides insights into how vaccination with HSPPC-96 can impact the peripheral immune compartment. Following 3 HSPPC-96 vaccinations, CD4 and CD8⁺ T-cell frequencies remain stable, but were associated with an expansion of a CD3⁺, CD4/CD8 double positive population, which was not seen in the nonresponder (Supplementary Fig. S3). Vaccination in responders was also associated with an increased frequency of NK cells, and a decrease in CD4⁺, CD25⁺, FoxP3⁺ regulatory T cells in circulation (Supplementary Fig. S2). Interestingly, the single nonresponder had significantly elevated regulatory T cells, as compared with the other treated patients (Supplementary Fig. S3).

Results of immunomonitoring data are summarized in Table 1 and reveal that patients vaccinated with HSPPC-96 show an immune response peripherally and suggest that this correlates with local pro-inflammatory...
Collectively our results suggest that surgically resected tumor from recurrent glioma patients contain adequate amounts of HSPPC-96 that can be safely administered as a source of adjuvant immunotherapy. Ex vivo, restimulation following such vaccination resulted in improved proinflammatory immune responses as indicated by NK and T-cell cytokine production and T-cell proliferation, suggesting that tumor specific T cells may clonally expand and release Th1 cytokines in vivo following vaccination. Long-term individual specific cellular immunity against a solid tumor after vaccination with autologous HSPPC-96 in humans has not been previously shown, appropriately controlled for the nonspecific adjuvant effects of HSPs.

Brain MRI scans with contrast were obtained at 8-week intervals on each patient or at shorter intervals if clinically indicated. Scans were reviewed for signs of tumor progression based on an increase in contrast enhancement. We used parameters similar to the recently published RANO criteria (26) and allowed for up to 20% increase in focal response. Collectively our results suggest that surgically resected tumor from recurrent glioma patients contain adequate amounts of HSPPC-96 that can be safely administered as a source of adjuvant immunotherapy. Ex vivo, restimulation following such vaccination resulted in improved proinflammatory immune responses as indicated by NK and T-cell cytokine production and T-cell proliferation, suggesting that tumor specific T cells may clonally expand and release Th1 cytokines in vivo following vaccination. Long-term individual specific cellular immunity against a solid tumor after vaccination with autologous HSPPC-96 in humans has not been previously shown, appropriately controlled for the nonspecific adjuvant effects of HSPs.

Figure 4. HSPPC-96 vaccination increases IFNγ producing T cells found infiltrating the tumor. Tumor infiltrating lymphocytes were isolated from clinical trial patients opting for a repeat surgery following vaccination and recurrence. TILs were cultured for 6 hours in the presence of BFA, and stained for CD3 and CD45. TILs were then permeabilized, stained for IFNγ, and analyzed by flow cytometry. A, top, gating of TILs for CD45⁺, CD3⁺ cells; bottom, percentage of CD3⁺, CD8⁺ cell producing IFNγ. B, summary of CD3⁺, CD8⁺ cell IFNγ production in all Phase I/II patients following surgery prior to and following HSPPC-96 vaccination. C, summary of CD3⁺, CD4⁺ cell IFNγ production in all Phase I/II patients following surgery prior to and following HSPPC-96 vaccination.

Figure 5. HSPPC-96 vaccination increases IFNγ producing T cells and NK cells found infiltrating the tumor. Tumor infiltrating lymphocytes were isolated from clinical trial patients opting for a repeat surgery following vaccination and recurrence. TILs were cultured for 6 hours in the presence of BFA, stained for CD3 and NKp46 (or CD56). TILs were then permeabilized, stained for IFNγ, and analyzed by flow cytometry. A, representative staining of TILs (top panels) and IFNγ production by NK cells (bottom panels). Plots show CD45⁺, CD3⁺, CD56⁺ gated cells. B, summary of CD3⁺, CD56⁺ lymphocyte production of IFNγ in all Phase I/II patients following surgery prior to and following HSPPC-96 vaccination.
enhancement provided that there was no associated clinical decline. An example of a true progressor, as compared with a patient with treatment effect after vaccination, is shown in Fig. 6.

**Discussion**

How might the results of our study impact the treatment of patients with GBM or other solid tumors? Successful cancer immunotherapy requires immunization with relevant antigen, but simply identifying the correct antigens is not sufficient. The tumor antigens must be delivered in a manner that can facilitate antigen presentation, typically by APCs at the site of vaccination. A number of other strategies have been devised to facilitate antigen delivery to APCs including *ex vivo* loading of dendritic cells followed by immunization, as well as simultaneous administration of cytokines and adjuvants with recombinant peptides to promote APC activation (14, 15, 27, 28). Cancer vaccines composed of HSPPCs have the distinct advantage of a specific mechanism to engage APCs.

Although the documentation of a polyvalent immune response is an important step, it is only the first of many necessary to facilitate efficacy. HSPPC-96 has been tested in large multicenter trials with modest evidence of clinical efficacy. However a closer examination of the clinical data published to date using HSPPC-96 would suggest that sufficient consideration to optimizing the patient population for vaccination was not put into the study designs. It is clear now that patients with minimal tumor burden are the best candidates for immunotherapy (29). Several groups have shown a correlation with tumor burden and an elevated level of regulatory T cells in circulation; which in turn act to suppress immunity (22, 30). A closer examination *post hoc* of both the renal cell carcinoma and melanoma trials using HSPPC-96 shows a statistically significant benefit to vaccination of patients with minimal or stable residual disease (23, 25). These trials lacked rigorous immunomonitoring necessary to document immune responses. Anecdotally, data from our study would seem to support the premise of treating patients with minimal tumor burden as well. The only patient to not show a peripheral immune response had intracranial tumor at time of initial vaccination, and relatively high levels of circulating regulatory T cells (patient #003). Another hurdle to effective immunotherapy can arise at the molecular level in which genetic features of tumor can make them suboptimal targets for immunotherapy. For example, tumor cells with loss of the tumor suppressor gene *PTEN* have increased expression of the immunosuppressive protein B7-H1, which in turn inhibits T-cell mediated killing of tumor cells (31, 32). The previously published reports on HSPPC-96 included trials with patients containing tumor burden in some cases, as well as no formal characterization of the immunoresistant phenotype of the tumors being treated.

There are limitations to our study worth mentioning, in particular the inability to conduct all of our assays for each patient. Because autologous HSPPC-96 was first and foremost used as a clinical agent in the trial, some patients did not have excess HSPPC-96 to use in multiple restimulation assays including ICS and CFSE proliferation assays. However this limitation is mitigated in part by restimulation experiments uniformly conducted on all the patients, using qPCR assays of proinflammatory transcripts with autologous HSPPC-96. The overall responses were determined based on all assays when available, but if unavailable, were based on significant responses to HSPPC-96 by qPCR. The rationale for this analysis was that patients who had a significant response as analyzed by qPCR also were statistically positive when analyzed by flow cytometry. However, given the small number of patients available for this study, patients were not analyzed for predictive time to recurrence or association with treatment effect following vaccination. This binary assignment will be refined on the analysis of the remainder of Phase II patients, as a larger patient population will allow further stratification of patients. These limitations also apply to our posttreatment site directed biopsies, which were conducted only on patients undergoing posttreatment surgery. In addition, in many cases the amount of tissue available for vaccine limited the utilization of tissue for exploratory analysis. Accordingly not all patients had pre-treatment tissue evaluated for TIL assessments shown in Figs. 4 and 5. Our study also highlights the limitations associated with applying a phase I surgically based study to a multiply recurrent GBM patient population that requires acquisition of viable tumor, with minimal treatment effect. Of the 28 patients enrolled in the study, only 12 received 4 vaccines with requisite follow-up for safety. We believe that this is more related to the patient population than the technology, as multiple recurrent GBM patients are more likely to have a mixture of treatment effect with tumor than patients who have their first recurrent after standard radiation and temozolomide. Recently a Phase II trial evaluating this technology for GBM patients at first recurrence

![Figure 6](image_url)

**Figure 6.** Representative MRI images of patient at enrollment, immediately postoperatively, and at true recurrence or treatment effect. T1-gadolinium enhanced images of a treated patient at enrollment (A), then immediately after surgical resection (B), at recurrence (C); T1-gadolinium enhanced images of patient treated with the HSP vaccine at enrollment (D), immediately postresection (E), and at pseudo-progression, which was proven on pathology to be treatment effect (F).
completed accrual and is currently in follow-up phase of analysis for overall survival determination. Our experience was substantially better with this patient population with vaccine production success approaching 90% of patients who underwent surgical resection (33). Another limitation to this study is that we cannot accurately predict or project the possible cost of the vaccine, beyond the standard costs associated with surgery and hospitalization. Because the product is not yet formally commercialized in the United States, and because much of the technology is proprietary, it is impossible to accurately predict what a patient could potentially be charged.

In conclusion, we have shown for the first time in humans that a tumor specific immune response to peptides bound to gp96 can be generated with autologous HSPPC-96 derived from a surgically resected solid tumor. There have been other reports describing immune responses after treatment with HSPPC-96 for patients with a variety of cancer types (20, 34–38). These studies collectively used a combination of phenotypic marker analysis of PBLs after vaccination or restimulation assays with a variety of antigens, including autologous tumor cell components and allogeneic cancer cell lines to assess immune responses. These important studies documented that HSPPC-96 can evoke an immune response, but lacked the recombinant gp96 control utilized in our study. There is abundant evidence of immune responses to human cancers and these responses may be individual patient specific, or shared among patients. Immune responses shared between patients have shown inconsistent correlation with clinical outcomes (19, 39); in contrast individual patient specific immune responses have shown excellent correlation with clinical outcomes (21, 40–43). Our observations are significant because they show a general mechanism to elicit individual patient-specific immune responses that seem to correlate with clinical outcome: Immune responders had a median survival of 47 weeks, as compared with 16 weeks for the nonresponder. Our study also confirms the safety and feasibility of an autologous HSPPC-96 approach for recurrent glioma patients. Our results, combined with the need for biologically active nontoxic adjuvant therapies, provide the impetus for further testing of autologous HSPPC-96 in recurrent glioma patients undergoing surgical resection. The documentation of a robust immune response suggests that re-evaluation of HSPPC-96 in optimally selected patients with other types of solid tumors is warranted. Finally, the advent of clinical grade antibodies targeting inhibitory proteins such as cytotoxic T-lymphocyte antigen 4 (CTLA-4; ref. 44) and PD-1 (45) provide practical approaches to amplifying the tumor specific immunity we describe (46, 47).

Disclosure of Potential Conflicts of Interest
No potential conflicts of interest were disclosed.

Authors' Contributions

Conception and design: A.T. Parsa
Development of methodology: C.A. Crane, V. Kivett, A.T. Parsa
Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): C.A. Crane, S.J. Han, B.J. Ahn, J. Oehlke, V. Kivett, A. Fedoroff, S.M. Chang, J. Clarke, M.W. McDermott, M.D. Prados, A.T. Parsa
Analysis and interpretation of data (e.g., statistical analysis, bioinformatics, computational analysis): C.A. Crane, S.J. Han, N. Butowski, S.M. Chang, M.D. Prados, A.T. Parsa
Writing, review, and/or revision of the manuscript: C.A. Crane, S.J. Han, N. Butowski, S.M. Chang, M.S. Berger, M.W. McDermott, M.D. Prados, A.T. Parsa
Administrative, technical, or material support (i.e., reporting or organizing data, constructing databases): V. Kivett, A. Fedoroff, N. Butowski, M.D. Prados, A.T. Parsa
Study supervision: V. Kivett, A. Fedoroff, N. Butowski, A.T. Parsa

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