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Lack of Protection following Passive Transfer of Polyclonal Highly Functional Low-Dose Non-Neutralizing Antibodies

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Abstract

Recent immune correlates analysis from the RV144 vaccine trial has renewed interest in the role of non-neutralizing antibodies in mediating protection from infection. While neutralizing antibodies have proven difficult to induce through vaccination, extra-neutralizing antibodies, such as those that mediate antibody-dependent cellular cytotoxicity (ADCC), are associated with long-term control of infection. However, while several non-neutralizing monoclonal antibodies have been tested for their protective efficacy in vivo, no studies to date have tested the protective activity of naturally produced polyclonal antibodies from individuals harboring potent ADCC activity. Because ADCC-inducing antibodies are highly enriched in elite controllers (EC), we passively transferred highly functional non-neutralizing polyclonal antibodies, purified from an EC, to assess the potential impact of polyclonal non-neutralizing antibodies on a stringent SHIV-SF162P3 challenge in rhesus monkeys. Passive transfer of a low-dose of ADCC inducing antibodies did not protect from infection following SHIV-SF162P3 challenge. Passively administered antibody titers and gp120-specific, but not gp41-specific, ADCC and antibody induced phagocytosis (ADCP) were detected in the majority of the monkeys, but did not correlate with post infection viral control. Thus these data raise the possibility that gp120-specific ADCC activity alone may not be sufficient to control viremia post infection but that other specificities or Fc-effector profiles, alone or in combination, may have an impact on viral control and should be tested in future passive transfer experiments.


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Introduction

While a large number of novel, broadly neutralizing antibodies have been described recently, the induction of such antibodies through vaccination in humans has proven difficult [1]. Neutralizing antibodies develop in approximately one third of infected through vaccination, extra-neutralizing antibodies, such as those that mediate antibody-dependent cellular cytotoxicity (ADCC), are associated with long-term control of infection. However, while several non-neutralizing monoclonal antibodies have been tested for their protective efficacy in vivo, no studies to date have tested the protective activity of naturally produced polyclonal antibodies from individuals harboring potent ADCC activity. Because ADCC-inducing antibodies are highly enriched in elite controllers (EC), we passively transferred highly functional non-neutralizing polyclonal antibodies, purified from an EC, to assess the potential impact of polyclonal non-neutralizing antibodies on a stringent SHIV-SF162P3 challenge in rhesus monkeys. Passive transfer of a low-dose of ADCC inducing antibodies did not protect from infection following SHIV-SF162P3 challenge. Passively administered antibody titers and gp120-specific, but not gp41-specific, ADCC and antibody induced phagocytosis (ADCP) were detected in the majority of the monkeys, but did not correlate with post infection viral control. Thus these data raise the possibility that gp120-specific ADCC activity alone may not be sufficient to control viremia post infection but that other specificities or Fc-effector profiles, alone or in combination, may have an impact on viral control and should be tested in future passive transfer experiments.

Non-neutralizing antibodies with innate immune–stimulating activities (e.g., ADCC-inducing antibodies) have been shown to play a crucial role in the clearance of several viral infections [9–11]. In HIV [12–16], antibodies with innate immune- recruiting activity have been detected in acutely infected individuals [12] and subjects who spontaneously control HIV infection in the absence of therapy [12,17]. Furthermore, strong ADCVI responses are associated with slower disease progression in long-term non-progressors [12,13,18–20], suggesting that antibodies with specific innate immune–activating properties may contribute to viral containment in vivo. Additionally, vaccine-elicited, non-neutralizing-ADCC-inducing antibodies [21–24] or the passive transfer of ADCC-inducing-non-neutralizing antibodies [25] have been repeatedly shown to contribute to antiviral control post-infection, further highlighting the importance of non-neutralizing antibody
effect of neutralizing antibodies on the control of HIV. Most recently, the immune correlates analysis of the RV144 vaccine trial demonstrated that ADCC activity, in the absence of vaccine-elicited IgA responses, was associated with a reduced risk of infection among vaccinees, supporting a role for vaccine-elicited non-neutralizing antibodies in protection for the first time [26].

Importantly, unlike neutralizing antibodies that target a limited network of neutralizing epitopes on the viral envelope, non-neutralizing antibodies may require the synergistic targeting of a much larger spectrum of epitopes to form an immune complex. Together, this targeting provides the avidity necessary to trigger the relatively low-affinity innate immune receptors, thereby allowing for rapid target cell elimination. Therefore, while non-neutralizing monoclonal antibodies, or combinations of several monoclonal antibodies, have afforded only limited protection from infection, it is plausible that a polyclonal pool of highly functional antibodies that target a broad range of epitopes may increase the ability of non-neutralizing antibodies to prevent or control HIV infection. Here we assessed whether polyclonal antibodies from a patient with robust non-neutralizing activity could provide protection from infection or mediate virological control following SHIV-SF162P3 challenge in rhesus macaques. Overall, passive transfer of a low-dose of a polyclonal pool of ADCC-inducing non-neutralizing antibodies did not provide sterilizing protection following intrarectal challenge with SHIV-SF162P3. Ancillary analyses demonstrate the selective persistence of IgG1 Abs and functional responses against gp120, but not gp41 after transfer in the blood, but not at the mucosa, potentially accounting for lack of protection from challenge.

Materials and Methods

Patients

Samples from a total of 15 elite controllers were included in this study, and IgG from one elite controller with robust innate–recruiting activity in the absence of neutralization was selected for passive transfer. In addition, a pool of IgG derived from five uninfected healthy individuals was used as a control. The MGH Institutional Review Board approved the study, and each subject provided written informed consent.

Antibody purification

For functional studies, human antibodies were isolated from 100 μL of plasma. For passive transfer, IgG isolation was performed on 100 mL of plasma from a single elite controller or 100 mL of pooled plasma from five healthy controls using protein A followed by protein A/G Sepharose columns. Rhesus macaque antibodies were isolated from plasma using a Melon Gel IgG Purification Kit, as recommended by the manufacturer (Thermo Scientific). No differences were observed in antibody subclass distribution or function following melon gel or protein A/G purification. IgGs were also tested for their ability to interfere or block SHIV/HIV infection in vitro, and no effect was observed.

Animals

Eleven Mamu-A*01-, B*17-, and B*08-negative adult Indian-origin rhesus monkeys were housed at the New England Primate Research Center, as recommended by the Guide for the Care and Use of Laboratory Animals. All studies were approved by the Institutional Animal Care and Use Committee (IACUC) of Harvard Medical School. Standard nutritious monkey diets were provided to each animal three times a day by skilled veterinary staff, in accordance with NEPRC standard operating procedures for veterinary care. No food or water deprivation occurred during the study. Animals were housed one per cage because socialized housing of animals under these circumstances increases the risk of transmission of the infectious agents, which could invalidate the study. Sources of enrichment included manipulation devices, foraging opportunities, food items, structural and environmental enhancements, and positive human interaction. Enrichment devices were rotated on a weekly basis and included toys, mirrors, radios, TV/VCRs, foraging boards, and a variety of complex foraging devices. To alleviate suffering, animals were fasted for 12 hours prior to any procedure and were given anesthesia, Ketamine HCL (10–20 mg/kg IM) for blood draws and colorectal biopsies. Following sample collections, the animals were monitored by the veterinary staff until recovered. Animals were humanely euthanized 3 months post antibody infusion by barbiturate overdose following anesthesia, in accordance with IACUC and HVMA guidelines.

Challenge experiment

Five rhesus macaques received intravenous transfer (IV) of 50 mg/kg of the antibodies isolated from the elite controller, five rhesus macaques received IV transfer of 50 mg/kg of antibodies isolated from the healthy controls and one rhesus macaque received 25 mg/kg of the neutralizing monoclonal antibody b12 one day prior to intrarectal challenge with SHIV-SF162P3. SHIV-SF162P3 was generated in rhesus PBMC and was administered intrarectally at an intermediate dose (7.3 log RNA copies/mL or 340 TCID50) designed to infect the majority but not all of the animals.

Sample collection

Plasma samples were collected on days 1, 3, 7, 14, 21, 28, 56 and 84 post-challenge and stored at −80°C. The plasma viral load was determined using the commercially available branched DNA (bDNA) kit (Siemens).

ADCVI assay

Peripheral blood mononuclear cells (PBMCs) were prepared from the whole blood of healthy control rhesus macaques using density gradient centrifugation and Ficoll-paque PLUS (GE Healthcare). CD4+ T cells were obtained using a CD8 Depletion Kit (Stem Cell Technology) and cultured (5×10^6/mL) for 3 days in RPMI 1640 supplemented with 10% fetal bovine serum, 2 mM L-glutamine, 100 μg/mL penicillin, 100 U/mL streptomycin, 10 mM HEPES, 50 U/mL IL-2 and 3 μg/mL PHA to activate the cells. On day 3, NK cells were isolated from the same donor rhesus macaque using a CD3 Depletion Kit (Stem Cell Technology). On the same day, the activated CD4+ T cells were infected with SHIV-SF162P3 at an MOI of 0.01 for 4 hours at 37°C. CD4+ T cells and NK cells were plated in 96-well round-bottom plates at an effectortarget ratio of 10:1 in the presence or absence of 50 μg/mL of antibody from the elite controller or the negative donor. Infected CD4+ T cells incubated with 50 μg/mL of antibody in the absence of effector cells served as a control to measure the capacity of each HIV-specific antibody to neutralize the virus and was complementary to the TZMBL assay, also aimed at measuring antibody neutralizing activity [27]. After 4 days of culture, the supernatant was collected, and viral replication was quantified using a p27 ELISA (Advanced Bioscience Laboratories). The inhibition of viral replication was calculated as follows: % Inhibition = (100−[100×p27 concentration in wells containing effectors, targets and antibody]/[p27 concentration in wells containing targets and antibody])

In addition, we measured the ability of 50 μg/mL of human plasma purified antibodies to recruit human NK cells and suppress
JRC SF or SF162 viral replication in activated human CD4 T cells. Briefly, peripheral blood mononuclear cells (PBMC) were prepared from the whole blood of HIV-negative donors using Ficoll Hypaque density gradient centrifugation. CD4s were obtained following 3 days of PBMCs culture at 5 x 10⁶/mL in RPMI 1640 supplemented with 10% fetal bovine serum, 2 mM L-glutamine, 100 µg/mL penicillin, 100 U/mL streptomycin, Hepes and 50 U/mL of IL-2 in the presence of 0.3 µg/mL of anti-CD3/8 antibodies. On day 3, autologous NK cells were isolated from the same donor using a Rosette Sep enrichment kit (STEM cell). On the same day, CD4 cells were infected with JRC SF or SF162 at a multiplicity of infection (MOI) of 0.01 for 4 hours at 37 degrees. The reaction was stopped, and the optical densities at 492 and 605 nm were read on a Tecan ELISA reader. The data were analyzed in Prism, and the EC50 was calculated for each sample (curve fit) using Prism, and the percent neutralization obtained was calculated after subtraction of the background as follows: 100 * [(RLU in the presence of both virus and antibody)/(RLU in the absence of antibody)]. Any antibodies in which we observed neutralization below 50% at 50 µg/mL were considered non-neutralizing. The values reported in Figure 1C correspond to the concentration of antibody necessary to achieve at least 50% neutralization of both the Tier 1A and Tier 2 viruses.

Antibody-dependent cellular phagocytosis (ADCP)

Biotinylated antigen was incubated with 1 µm yellow-green fluorescent neutravidin beads (Invitrogen) overnight. The beads were then washed and resuspended at a final dilution of 1:100 in PBS-BSA. Antibodies and 9 x 10⁵ antigen-labeled beads were mixed in a round bottom 96-well plate, and the plate was incubated for 2 hours. THP-1 cells (2 x 10⁵ cells) were then added to each well in a final volume of 200 µL, and the plate was incubated overnight under standard tissue culture conditions. The next day, half the culture volume was removed and replaced with 100 µL of 4% paraformaldehyde before the plates were analyzed on a BD LSRII equipped with an HTS plate reader. For analysis, the samples were gated on live cells, and the proportion of THP-1 cells phagocytosing beads was determined. The data represents the results of two separate experiments for which a phagocytic score was calculated as follows: (% bead positive x MFI bead positive [29]).

Rapid fluorometric antibody-dependent cellular cytotoxicity (RFADCC)

The rapid fluorometric ADCC (RFADCC) assay was performed as previously described [30]. Briefly, 1 x 10⁶ CEM.NKr cells (Dr. Peter Cresswell through the AIDS Reagent Program, Division of AIDS, NIAID, NIH; Catalog #3957, HIV-1G from NABI and NHLBI) were used as a positive control. After six washes, 100 µL of horseradish peroxidase–conjugated anti-human IgG (1:500, diluted in PBS; BD Pharrmingen) was added to each well, and the plate was incubated for 1 hour at room temperature, washed and developed by the addition of 50 µL of O-phenyl-enediamine diluted in 11 mL PBS. The reaction was stopped, and the optical densities at 492 and 605 nm were read on a Teco ELISA reader. The data were analyzed in Prism, and the EC50 was calculated for each sample as follows: Y = Min+[(Max−Min)/(1+10⁶ LogEC50−X)] where Y is the observed value, Min is the lowest observed value, Max is the highest observed value, X is the value when the response is halfway between Max and Min and LogEC50 is the logarithm of the EC50.

TZM-bl cell–based neutralization assay

The neutralizing capacity of antibodies purified from the plasma of elite controllers was assessed using a modified TZM-bl assay [4,28]. Briefly, TZM-bl cells (1 x 10⁶) were plated in 96-well plates, cultured overnight, and neutralization assays were performed using 10 time dilutions of antibody, starting at a concentration of 1 mg/mL. The diluted antibodies were mixed with 0.003 MOIs of a fully replicating Tier 1A (SF162), Tier 2 (JRC FS), or SHIV-SF162P3 virus, after which the antibodies and virus were transferred onto TZM-bl cells. The controls included cells cultured in the absence of virus, in the absence of antibodies (negative control) or in the presence of 5 µg/mL of the b12 or b6 monoclonal antibodies (positive controls). After a 24-hour incubation at 37°C, the cells were analyzed for luciferase expression. The data were analyzed using non-linear regression (curve fit) using Prism, and the percent neutralization obtained was calculated after subtraction of the background as follows: 100 * [1−[(RLU in the presence of both virus and antibody)/(RLU in the absence of antibody)]]. Any antibodies in which we observed neutralization below 50% at 50 µg/mL were considered non-neutralizing. The values reported in Figure 1C correspond to the concentration of antibody necessary to achieve at least 50% neutralization of both the Tier 1A and Tier 2 viruses.
was injected over the chip surface at 7 μL/min for 10 min to coat. Unreacted sites were subsequently deactivated by injecting 25 μL of 1 M ethanolamine (pH 8.5) at 7 μL/min. 125 ug/mL of antibody were then run over the chip at a flow rate of 25 μL/min. The affinity (RU), on-rate (K₉), off-rate (Kᵦ) and overall binding affinity (K₉) was compared among the different groups.

Antibody dependent complement deposition assay

The ability of antibodies to bind and activate the complement was determined by the C₃b deposition on gp120-pulsed target cells. Briefly, 1 × 10⁶ CEM.NKr cells were pulsed with 6 μg of recombinant gp120 YU-2 or SF162 for 1 hour at room temperature and then washed twice in cold R10. Uncoated CEM.NKr cells were used as a negative control. Plasma from healthy individuals was collected and used as a source of complement for the assay. 25 μg of both the EC antibodies selected for the in vivo challenge and the antibodies purified from each 11 monkeys were added to 10⁵ CEM.NKr cells in the presence of plasma diluted 1:10 in veronal buffer supplemented with 0.1% gelatin for 20 minutes at 37 degrees. Cells were washed and stained with a FITC-conjugated C₃b antibody for 15 minutes, washed and fixed in 4% PFA. HIVIG was used as a positive control for this assay and heat inactivated plasma as well as antibodies from healthy individuals were both used as negative controls. The data are the results of two separate experiments.

Statistical analyses

All statistical analyses were performed using GrapPad Prism 5.0 software. Spearman rank correlation was used. Comparative analyses of the viremia between both groups were performed using an unpaired two-tailed t-test with 95% confidence intervals. P-values were two-sided and not adjusted for multiple testing. P-values less than 0.05 were considered statistically significant.

Results

Characterization of polyclonal ADCVI-inducing non-NAbs for passive transfer experiments

While previous passive transfer experiments in which non-neutralizing, ADCC-inducing antibodies were transferred failed to protect macaques from infection [25], these experiments were performed in neonatal rhesus macaques in which immature NK cells with poor functionality or insufficient antibodies may have contributed to an incapacity to form the immune complexes necessary to stimulate the low affinity Fc receptors. Therefore, we aimed to test whether a polyclonal pool of human non-neutralizing antibodies could provide protection from infection. Previous reports have shown that ADCC-inducing antibodies are significantly enriched in subjects who spontaneously control HIV infection in the absence of therapy [12,13,17]. Since functional non-neutralizing antibodies from normally progressing macaques have led to a reduction in viremia...
sterilizing protection [8,31-33] and allowing for the delivery of polyclonal antibodies from a single donor to 5 animals. One animal received 25 mg/kg of the monoclonal antibody b12 that was used as an internal control since the protection of b12 has been previously reported to mediate protection from infection in vivo [8]. All antibodies were delivered 1 day before a single intermediate-dose intrarectal challenge with SHIV-SF162P3 virus; viral infection was monitored at days 1, 3, 7, 14, 28, 56 and 84 days post transfer, and samples were collected at the same time points.

No difference was observed in the frequency of infected macaques among animals that received antibodies from EC10 (four of five infected) or the antibodies from HIV-negative individuals (three of five infected) (Figure 3A and B, respectively). In contrast, the single, proof of concept, control animal that received the b12 antibody remained uninfected with no detectable viremia at month 3 post infection confirming that the challenge virus can be blocked by a well-characterized monoclonal antibody (Figure 3C).

Additionally, no differences were observed in peak viremia (EC Ab-treated, mean 1.041+007 copies/mL; HIV-NEG Ab-treated, mean 8.831+006 copies/mL) or viral set point (EC Ab-treated, mean 1.44808 copies/mL; HIV-NEG Ab-treated, mean 1.693e+06 copies/mL) following infection (Figure 3). Moreover, the area under the curve (AUC) analysis of viral loads in the monkeys receiving the EC Abs (median AUC = 1.53e+007) compared to the infected monkeys that received the HIV-NEG antibodies (AUC = 3.96e+007) were not statistically different (Figure 3C). Thus, the passive transfer of polyclonal non-neutralizing antibodies from an elite controller with potent innate immune-recruiting activity was not able to protect rhesus macaques from or after infection following a stringent rectal SHIV-SF162P3 challenge.

gp120-specific antibody titers and function do not correlate with post-infection viral control

Previous data suggest that the passive transfer of non-neutralizing, ADCC-inducing antibodies leads to post-infection viral control [25,34]. To investigate parameters that may have accounted for the lack of protection, we next evaluated the dynamics of passively transferred polyclonal, non-neutralizing antibodies. First, we measured gp120-specific antibody titers in the plasma of all 7 infected monkeys. As expected, no gp120-specific antibodies were detectable in the plasma of macaques that received antibodies from HIV-negative controls at early time points; however, two of the control Ab–treated rhesus macaques mounted gp120-specific antibody responses at Day 21 (Figure 4A). By contrast, gp120-specific antibodies were detectable at Day 1 post-transfer in animals receiving the elite controller antibodies, and these antibody levels slowly decayed over the study period. Some variation was observed in the plasma antibody levels as early as Day 3, suggesting differential antibody-clearance among the macaques (Figure 4Aii). Moreover, nearly all of the circulating HIV-specific antibodies in the macaques were of the IgG1 subclass, suggesting that other antibody subclasses, which were detectable prior to transfer, may have been cleared rapidly after transfer (Figure 4B-E). Mucosal gp120-specific antibodies were not detectable in the macaques at Day 7 post-transfer, suggesting that either the antibodies penetrated the mucosa poorly, thereby providing only limited protection at the site of inoculation, or that the antibodies were cleared rapidly following transfer (data not shown). Thus, in spite of the detection of high gp120-specific antibody titers at early time points in all monkeys, no antibodies were detected at mucosal barriers and only IgG1 antibodies persisted in the blood.
Next we evaluated the functional properties of transferred Abs, including gp120-specific ADCC, ADCP and complement deposition as well as gp41-specific ADCC and ADCP activities. As expected, no ADCC or ADCP activity was detected in the control animals (Figure 4Fi and 4Gi, respectively). However, while both gp120-specific ADCC and ADCP activities were observed in all
four macaques were infected following the transfer of EC antibodies (Figure 4Fii and 4Gii, respectively), these Fc mediated functions correlated only weakly with viral control post infection. Additionally, while complement activity was detected in the EC Ab preparation prior to infusion, no complement deposition was detected in any of the animals following antibody infusion suggesting that antibody mediated complement deposition were rapidly cleared following the passive transfer (data not shown).

Similarly, while gp41-specific ADCP activity was readily detectable prior to infusion, and gp41-specific Ab titers were clearly detectable post-infection (Figure 3A), no gp41-specific ADCP activity or antibody dependent NK cell activation was detectable following passive transfer in the monkeys that received the EC antibodies (Figure 3B and 3C, respectively). These data suggest the potential preferential clearance of gp41-specific functional antibodies and all complement activating antibodies following passive transfer.

Overall, these data show that the passive transfer of a polyclonal pool of non-neutralizing antibodies with potent ADCVI activity did not protect from infection following a stringent SHIV-SF162P3 challenge. Antibody transfer dynamics revealed limited delivery of antibodies to the rectal mucosa and the selective loss of antibody-subpopulations following passive transfer potentially limiting the functional properties of the transferred polyclonal antibodies. These data raise the possibility that either non-neutralizing antibodies may not provide protection from or after infection or that other Fc mediated antiviral functions, alone or in combination, may have a greater impact on viral control. Thus, passive transfer experiments in rhesus macaques using polyclonal, ADCC-inducing antibodies demonstrated unexpected antibody clearance post-transfer resulting in minimal antibody delivery to the rectal mucosa, selective loss of all non-IgG1 antibody subclasses in the blood, selective depletion of gp41-specific ADCP antibodies, and elimination of all complement activating antibodies. Such alterations in antibody subpopulations could profoundly alter in vivo functionality and therefore protective activity. However, despite this alteration, weak, but insignificant associations, were observed between gp120-specific titers and Fc-receptor binding characteristics with post-infection viral control (data not shown).

While the passive transfer of broadly neutralizing antibodies has been successful in mediating sterilizing protection in rhesus macaques, vaccines that elicit these responses have proven elusive. More recently, vaccine strategies that induce non-neutralizing functional antibodies have shown only limited success in preventing infection [21–24]. However, unlike neutralizing antibodies that simply block a limited number of viral epitopes on the surface of a virus, non-neutralizing antibodies must form avid immune complexes that are able to recruit the low-affinity receptors or innate immune proteins necessary for their function. Therefore, it is not surprising that the transfer of a polyclonal pool of non-neutralizing antibodies with the capacity to form these immune complexes may be required for protection. However, while the passive transfer of polyclonal sera, such as IVIG, is usually 8 times higher than the dose selected here (400 mg/kg), the bioactive dose of sialated anti-inflammatory antibodies or pathogen-specific antibodies are only a minute fraction of the total transferred antibodies [44]. Notably, it has been previously shown that HIV-neutralizing activity to protection from infection. However, these negative results may be the result of several inherent difficulties associated with study design using non-neutralizing antibodies, including 1) the use of single monoclonal antibodies [31,32,36] [37] or pooled monoclonals [33,38–42] [43], which target a limited number of epitopes and therefore induce poor immune complex formation, and 2) the use of NHP polyclonal sera with ADCC activity, which has not been associated with the durable antiviral activity observed in long-term non-progressors. To circumvent these problems, we performed a passive transfer experiment in rhesus macaques using polyclonal, ADCC-inducing antibodies isolated from an elite controller that exhibited non-neutralizing control of infection. No sterilizing protection from infection was observed following a rectal SHIV-SF162P3 challenge. Subsequent ex vivo analysis of transferred antibodies demonstrated unexpected antibody clearance post-transfer resulting in minimal antibody delivery to the rectal mucosa, selective loss of all non-IgG1 antibody subclasses in the blood, selective depletion of gp41-specific ADCP antibodies, and elimination of all complement activating antibodies. Such alterations in antibody subpopulations could profoundly alter in vivo functionality and therefore protective activity. However, despite this alteration, weak, but insignificant associations, were observed between gp120-specific titers and Fc-receptor binding characteristics with post-infection viral control (data not shown).

Figure 3. Kinetics of plasma viremia following SHIV-SF162P3 challenge. 50 mg/kg of antibodies purified from the selected elite controller (A) or from HIV-negative individuals (B) were passively transferred intravenously one day prior to the challenge with SHIV-SF162P3 in 5 rhesus macaques each. The plasma viremia was measured 14 days before and 1, 3, 7, 14, 21, 28, 56 and 84 days after antibody transfer. No viremia was detected in the animal that received 25 mg/kg of the b12 monoclonal antibodies used as a positive control. The area under the curve (AUC) of viral loads was measured in the 4 infected monkeys that received the EC antibodies and the 3 infected monkeys that received HIV-NEG antibodies (C). An unpaired two-tailed t-test with 95% confidence intervals was used to compare the AUC between both groups.

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Discussion

 Recent results from the correlates analysis of the RV144 vaccine trial [35] pointed to a protective role of non-neutralizing antibodies in the control of HIV infection. Specifically, in the absence of vaccine-elicited IgA responses, several features of the antibody functional profile, including ADCC activity, were correlated with a reduced risk of infection. However, over the past decade, attempts to examine the protective role of non-neutralizing antibodies in the non-human primate model [21,22,24] have failed to mechanically link antibodies that lack
specific antibodies constitute approximately 2% of the serum antibody pool [44], suggesting that the total fraction of HIV-specific antibody transferred in this study may have only approximated 1 mg/kg, at roughly less than half of the dose of b12 required to achieve sterilizing protection, potentially accounting for reduced protective efficacy. While these levels may be sufficient to block infection by some of the newer potent broadly neutralizing antibodies [45], significantly higher levels are likely
required to generate enough immune complexes able to eliminate incoming virus. Recently, passive immunization in macaques with a polyclonal pool of anti SHIV IgG conclusively showed the critical nature of the transferred antibody dose [46]. Of note, the study demonstrated that passive transfer of 25 mg/kg of antibodies increased acquisition in a complement dependent manner, while partial protection was observed at 625 mg/kg, where HIV-specific antibodies still only constituted a transfer of 12.5 mg/kg. This data offers compelling evidence that protection can be achieved with non-neutralizing antibodies, and that perhaps the transfer or induction of similar doses of highly functional antibodies may offer even greater protection from infection. Thus future passive transfer with higher levels of elite controller antibodies, at ten-fold higher levels, may be required to achieve protection from infection, but may show enhanced protection from infection in the absence of neutralization.

Because most HIV transmissions occur across mucosal surfaces, the development of a successful, protective vaccine will likely require the presence of HIV-specific antibodies that harbor potent functional properties at the mucosal barrier. In the current study, transferred EC antibodies were not detected in the rectal mucosa at Day 7, potentially contributing to the lack of observed protection. Thus, it is plausible that either only low levels of the systemically administered antibodies reached the rectal mucosa and/or that the antibodies that reached the mucosa were cleared more rapidly in tissues compared to the blood. Therefore, future non-neutralizing antibody transfer studies may aim to deliver antibodies directly at the site of inoculation to define the critical humoral parameters involved in antiviral control.

While no protective activity of the passively transferred antibodies was detected, ancillary analyzes revealed that gp120 specific, but not gp41 specific, ADCC and ADCP were detectable in all 4 infected monkeys that received the EC Abs following infection, 2 functions that have been previously shown to control HIV replication in both humans and rhesus macaques [7,12,17,47]. Of note, a blip in the ADCP activity was observed in one of the monkeys that received the HIV-negative antibodies following challenge, which was repeatedly shown to be non-HIV-specific. Because the HIV envelope protein is highly glycosylated, it is plausible that in this animal, natural antibodies may have emerged following infection, mimicking some of the autoimmune-like antibody responses documented in subjects that elicit broadly neutralizing antibody response against HIV [48]. Additionally, while Fc mediated antiviral properties of antibodies are tightly linked to their ability to bind to Fc-receptors and that we observed a weak but not statistically significant correlation between Fc-receptor binding and post infection viral control (data not shown), future efforts aimed at selecting sera with potent Fc-receptor binding, as a surrogate of robust Fc mediated activity, may help conclusively define the role for non-neutralizing antibodies in protection from infection.

Thus overall, no sterilizing protection was observed following the intravenous passive transfer of a low dose of non-neutralizing ADCVI-mediating antibodies using a rectal SHIV-SF162P3 challenge. While previous studies have pointed toward a crucial role for ADCC activity in viral control in both humans and rhesus monkeys, future experiments using an increased concentration of functional antibodies, both peripherally and at the site of challenge, may contribute to lowered viremia following infection.
Despite a lack of protection, this study provides critical insights for the design of future animals studies aimed at conclusively defining the antiviral effect of polyclonal non-neutralizing HIV-specific antibodies.

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References


Author Contributions

Conceived and designed the experiments: ASD DHB GA. Performed the experiments: ASD DHB GA. Analyzed the data: ASD TJS MG MEA GA. Contributed reagents/materials/analysis tools: ASD DHB GA. Wrote the paper: ASD GA. Read and gave comments on the paper: HS.