Clinical Grade Treg: GMP Isolation, Improvement of Purity by CD127\textsuperscript{pos} Depletion, Treg Expansion, and Treg Cryopreservation

Jorieke H. Peters\textsuperscript{1}, Frank W. Preijers\textsuperscript{2}, Rob Woestenenk\textsuperscript{2}, Luuk B. Hilbrands\textsuperscript{3}, Hans J. P. M. Koenen\textsuperscript{1}, Irma Joosten\textsuperscript{1*}

\textsuperscript{1}Department of Bloodtransfusion and Transplantation Immunology, Radboud University Nijmegen Medical Centre, Nijmegen, the Netherlands, \textsuperscript{2}Central Hematology Laboratory, Radboud University Nijmegen Medical Centre, Nijmegen, the Netherlands, \textsuperscript{3}Department of Nephrology, Radboud University Nijmegen Medical Centre, Nijmegen, the Netherlands

Abstract

Background: Treg based immunotherapy is of great interest to facilitate tolerance in autoimmunity and transplantation. For clinical trials, it is essential to have a clinical grade Treg isolation protocol in accordance with Good Manufacturing Practice (GMP) guidelines. To obtain sufficient Treg for immunotherapy, subsequent \textit{ex vivo} expansion might be needed.

Methodology/Principal Findings: Treg were isolated from leukapheresis products by CliniMACS based GMP isolation strategies, using anti-CD25, anti-CD8 and anti-CD19 coated microbeads. CliniMACS isolation procedures led to 40–60\% pure CD4\textsuperscript{pos}CD25\textsuperscript{high}FoxP3\textsuperscript{pos} Treg populations that were anergic and had moderate suppressive activity. Such CliniMACS isolated Treg populations could be expanded with maintenance of suppressive function. Alloantigen stimulated expansion caused an enrichment of alloantigen-specific Treg. Depletion of unwanted CD19\textsuperscript{pos} cells during CliniMACS Treg isolation proved necessary to prevent B-cell outgrowth during expansion. CD4\textsuperscript{pos}CD127\textsuperscript{pos} conventional T cells were the major contaminating cell type in CliniMACS isolated Treg populations. Depletion of CD127\textsuperscript{pos} cells improved the purity of CD4\textsuperscript{pos}CD25\textsuperscript{high}FoxP3\textsuperscript{pos} Treg in CliniMACS isolated cell populations to approximately 90\%. Expanded CD127\textsuperscript{neg} CliniMACS isolated Treg populations showed very potent suppressive capacity and high FoxP3 expression. Furthermore, our data show that cryopreservation of CliniMACS isolated Treg is feasible, but that activation after thawing is necessary to restore suppressive potential.

Conclusions/Significance: The feasibility of Treg based therapy is widely accepted, provided that tailor-made clinical grade procedures for isolation and \textit{ex vivo} cell handling are available. We here provide further support for this approach by showing that a high Treg purity can be reached, and that isolated cells can be cryopreserved and expanded successfully.


Introduction

Regulatory T cells (Treg) play a critical role in various immunological processes, particularly in maintaining homeostasis and self-tolerance. Immunotherapy based on Treg infusion is therefore a potential treatment for many immune disorders. This approach has been proven successful in animal models of stem cell transplantation [1–7], solid organ transplantation [8,9] and autoimmunity [6,10–13]. Therapeutic application in humans requires strategies, using anti-CD25, anti-CD8 and anti-CD19 coated microbeads. CliniMACS isolation procedures led to 40–60\% pure CD4\textsuperscript{pos}CD25\textsuperscript{high}FoxP3\textsuperscript{pos} Treg populations that were anergic and had moderate suppressive activity. Such CliniMACS isolated Treg populations could be expanded with maintenance of suppressive function. Alloantigen stimulated expansion caused an enrichment of alloantigen-specific Treg. Depletion of unwanted CD19\textsuperscript{pos} cells during CliniMACS Treg isolation proved necessary to prevent B-cell outgrowth during expansion. CD4\textsuperscript{pos}CD127\textsuperscript{pos} conventional T cells were the major contaminating cell type in CliniMACS isolated Treg populations. Depletion of CD127\textsuperscript{pos} cells improved the purity of CD4\textsuperscript{pos}CD25\textsuperscript{high}FoxP3\textsuperscript{pos} Treg in CliniMACS isolated cell populations to approximately 90\%. Expanded CD127\textsuperscript{neg} CliniMACS isolated Treg populations showed very potent suppressive capacity and high FoxP3 expression. Furthermore, our data show that cryopreservation of CliniMACS isolated Treg is feasible, but that activation after thawing is necessary to restore suppressive potential.


Editor: Derya Unutmaz, New York University School of Medicine, United States of America

Received June 24, 2008; Accepted August 18, 2008; Published September 8, 2008

Copyright: © 2008 Peters et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: This study was supported by a grant of the Dutch Kidney Foundation (C05-2106). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: I.Joosten@abti.umcn.nl
immune responses are cytotoxic CD8<sup>pos</sup> T cells and CD4<sup>pos</sup>
conventional T cells, and contamination of CliniMACS isolated
Treg populations with these cells should be avoided for
immunotherapy in patients other than stem cell recipients.
Likewise, contamination of the isolate with B cells could lead to
the infusion of activated B cells with potential adverse immuno-
logical consequences.

Although CliniMACS based Treg isolation from leukapheresis
products will yield large numbers of Treg, ex vivo expansion of
these cells prior to infusion might still be necessary to obtain
sufficient numbers of Treg for effective immunotherapy. Treg can
be expanded efficiently using polyclonal stimulation [16–19].
However, antigen-specific Treg have been shown to be far more
efficient than polyclonal Treg in animal models [3,5–7,12,13]. In
allogeneic transplantation, the target antigens are known (mainly
foreign HLA) and human alloantigen-specific Treg can be
obtained by expansion using stimulation with alloantigen [20,21].

For practical reasons, it would be convenient or even necessary
to perform the leukapheresis procedure weeks/months before
the transplantation or treatment and store the Treg until they are
needed. Currently, information on cryopreservation of Treg is
lacking.

In the current study, we confirm that GMP Treg isolation using
standard CliniMACS procedures results in moderately pure Treg
populations. Here, we show that purity of CliniMACS isolated
Treg can be improved by depletion of CD127<sup>pos</sup> cells. In addition,
we show that CliniMACS isolated Treg can be expanded with
maintenance of suppressive function using polyclonal or alloantig-
gen stimuli in the presence of IL-2. Depletion of CD19<sup>pos</sup> B cells
during CliniMACS Treg isolation appears to be a prerequisite to
prevent B cell outgrowth during expansion. Furthermore, we show
that cryopreservation of Treg is feasible, but that the cells require
activation to restore suppressive potential.

**Results**

**Isolation of Treg using CliniMACS yields 40–60% pure
CD4<sup>pos</sup>CD25<sup>high</sup> Treg populations with suppressive
activity**

Treg immunotherapy will demand very high numbers of highly
pure Treg populations isolated in a GMP manner. To obtain large
numbers of Treg with optimal purity, we performed
CD4<sup>pos</sup>CD25<sup>high</sup> T cell isolation from healthy donor leukapheresis
products using the GMP CliniMACS system. The most straight-
forward strategy to enrich for Treg would be a one step positive
selection of CD25<sup>pos</sup> cells out of leukapheresis products. However,
this strategy would unintentionally result in contaminating
(activated) cytotoxic CD8<sup>pos</sup> T cells in the isolated Treg
populations. Therefore, our initial CliniMACS isolation strategy
consisted of two steps: first a CD8 depletion step to exclude
CD8<sup>pos</sup> effector T cells from the isolated cell populations, followed
by a CD25 enrichment step to enrich for CD4<sup>pos</sup>CD25<sup>high</sup> Treg
(referred to as CliniMACS<sup>8/25</sup>). For comparison, a laboratory
scale MiniMACS based Treg isolation protocol was also
performed (referred to as MiniMACS).

Leukapheresis products contained on average 3%
CD4<sup>pos</sup>CD25<sup>high</sup> regulatory T cells (Figure 1 and Table 1). Less
than 0.1% CD8<sup>pos</sup> cells were present in the isolated CliniMACS<sup>8/25</sup>
populations. While 80% of CliniMACS<sup>8/25</sup> cells was
CD4<sup>pos</sup>CD25<sup>pos</sup>, only 40–60% was CD4<sup>pos</sup>CD25<sup>high</sup> (Figure 1A
and Table 1). MiniMACS based Treg isolation from the same
leukapheresis product yielded a higher Treg purity with 90%
CD4<sup>pos</sup>CD25<sup>high</sup> cells. CliniMACS<sup>8/25</sup> populations expressed
lower levels of FoxP3 as compared to MiniMACS isolated Treg
populations (Figure 1A).

A hallmark of CD4<sup>pos</sup>CD25<sup>high</sup> Treg is their anergic phenotype,
defined as low proliferative capacity upon T cell receptor
stimulation alone as compared to Tconv cells, which can be
restored by the addition of exogenous IL-2. Both CliniMACS<sup>8/25</sup>
and MiniMACS populations were anergic (Figure 1B).

Suppressive capacity of Treg populations was determined by
titration of Treg into co-cultures of autologous CD4<sup>pos</sup>CD25<sup>neg</sup>
responder T cells stimulated with allogeneic stimulator PBMC. As
shown in Figure 1C, Treg populations isolated with the
CliniMACS<sup>8/25</sup> strategy were moderately suppressive, reaching
50% suppression at a 1:1 Tresp:Treg ratio, while MiniMACS
isolated Treg populations were more potent, with 50% suppression
at Tresp:Treg ratios of approximately 4:1.

**Expansions of CliniMACS Treg with either polyclonal or
alloantigen stimulation increases cell numbers while
suppressive activity is retained**

CliniMACS Treg isolation strategies yield high numbers of
Treg, but these numbers might still be too low for therapeutic
purposes. This issue can be overcome by ex vivo expansion of Treg.
To analyze expansion potential and effects of expansion on
phenotypic and functional characteristics, CliniMACS<sup>8/25</sup> isolated
Treg populations were activated using either polyclonal stimula-
tion (anti-CD3+anti-CD28 mAb coated microbeads) or alloanti-
gen stimulation (irradiated PBMC from an HLA-mismatched
donor), in the presence of exogenous IL-2.

Polyclonal and alloantigen stimulated expansion cultures yielded
similar cell numbers (Table 2). CliniMACS<sup>8/25</sup> populations
increased about 30-fold in cell numbers in ten days. The
phenotype of expanded CliniMACS<sup>8/25</sup> populations is depicted in
Figure 2A. CD25 expression was high in both CliniMACS<sup>8/25</sup>
and MiniMACS populations, while the expression of FoxP3 was lower
in expanded CliniMACS<sup>8/25</sup> cells as compared to expanded
MiniMACS populations. After expansion, all Treg populations
remained anergic (Figure 2B). CliniMACS<sup>8/25</sup> and MiniMACS
populations suppressed alloantigen driven responder T cell
proliferation to a similar extent (Figure 2C). Notably, alloantigen
expanded Treg populations showed higher suppressive capacity in
alloantigen driven responder T cell responses as compared to
polyclonally expanded Treg (>75% suppression at a Tresp:Treg
ratio of 16:1 versus 50% suppression at Tresp:Treg ratios a
Tresp:Treg ratio of 8:1, respectively, Figure 2C). This indicates
that the alloantigen expanded cell populations were enriched for
alloantigen-specific Treg. As our group has shown previously, the
low proliferation observed after addition of alloantigen expanded
Tconv can be explained by distinct culture kinetics with an earlier
proliferation peak and a net result of lower counts at day 5 [21].

It would be convenient for Treg immunotherapy to be able to
store Treg cells prior to manipulation and/or infusion. The
suppressive capacity of cryopreserved CliniMACS Treg was
impaired (Figure 3), and could not be regained by cell resting
for up to seven days in culture medium. However, expansion of
cryopreserved CliniMACS cells restored suppressive capacity.

**Depletion of CD19<sup>pos</sup> cells during CliniMACS Treg
isolation is necessary to prevent B cell contamination**

After CliniMACS<sup>8/25</sup> isolation procedures, less than 3% B cells
were present in isolated populations, these numbers increased after
expansion to 5 to 10% (Figure 4A). In order to remove B cells from
our CliniMACS isolated Treg populations, we tested the efficacy of
CD19<sup>pos</sup> B cell depletion in the CliniMACS isolation procedure.
Clinical Grade Treg

Figure 1. Phenotypic and functional characteristics of freshly CliniMACS isolated Treg. Treg were isolated from leukapheresis products in GMP CliniMACS-based or non-GMP MiniMACS-based isolation procedures. Data from a typical isolation are shown (N = 3). (A) Cell surface expression of CD4 and CD25 and intracellular expression of FoxP3. (B) Proliferative capacity upon stimulation with allogeneic PBMC in the absence or presence of exogenous IL-2, measured at day 5 of culture. (C) Suppressive capacity in co-cultures of autologous naïve CD4posCD25neg Tresp stimulated with allogeneic PBMC. Significant differences are indicated by asterisks. In figure C, open and filled asterisks refer to Tconv (used as control for the addition of cells) versus MiniMACS or CliniMACS8/25, respectively.
doi:10.1371/journal.pone.0003161.g001

In this strategy, first CD8pos and CD19pos cells were depleted, followed by enrichment of CD25pos cells (referred to as CliniMACS8/19/25). Less than 0.5% B cells were present after these isolations (see Table 1 and Figure 4B) and no substantial B cell contaminations arose after either polyclonal or alloantigen expansion (see Table 2 and Figure 4B). CliniMACS8/19/25 populations were similar to CliniMACS8/25 cells with respect to the phenotype, anergic state and suppressive potential, both directly after isolation as well as after expansion (data not shown). Thus, CD19pos depletion effectively prevents B cell contaminations in CliniMACS Treg populations after isolation and after expansion.

Depletion of CD127pos cells improves CliniMACS Treg purity
CD4posCD25neg/lowFoxP3neg/low Tconv cells were the major contaminating cell type in CliniMACS isolated Treg (40-60% of the isolated populations, see Figure 1). Recently, it has been described that Tconv express the IL-7 receptor alpha-chain CD127, while Treg cells do not express CD127 [22,23]. Indeed,
CliniMACS isolated populations contained both CD127neg and CD127pos cells, reflecting the presence of both Treg and Tconv cells (Figure 5A). To improve the purity of Treg isolated with CliniMACS, we hypothesized that depletion of CD127pos cells could be employed to exclude contaminating T cells. Because anti-CD127 CliniMACS beads are currently not available, we depleted CD127pos cells from CliniMACS isolated cell populations by FACs.

As shown in Figure 5A, this procedure indeed enabled separation of Treg from Tconv cells. In contrast to CD127pos cells, the majority of CliniMACS CD127neg cells showed a Treg phenotype: CD4posCD25high and FoxP3pos. Since we used cryopreserved CliniMACS populations for these experiments, we expanded the populations prior to functional characterization. After expansion, CD127neg populations retained a high Treg purity, as evidenced by high expression of CD25 and FoxP3 (Figure 5B). In contrast to CD127pos populations, CD127neg populations were anergic after expansion (Figure 5C). As expected, CD127 depletion enhanced suppressive potential, as shown by the significantly higher suppressive capacity of CD127neg populations (Figure 5D).

### Discussion

Immunotherapy using \textit{ex vivo} activated and/or expanded CD4posCD25high regulatory T cells appears promising, not only in stem cell transplantation, but also for a number of autoimmune disorders. To be optimally effective, the availability of tailor-made clinical grade procedures is a prerequisite. As previously reported [14,15], CliniMACS GMP Treg isolation strategies based on CD25pos enrichment typically result in 40–60% pure Treg with moderate suppressive activity.

### Table 1. Enrichment of CD4posCD25high Treg by CliniMACS isolation.

<p>| Percentage of cells with indicated phenotype (SD) | CD4pos | CD4pos | CD4pos | CD8pos | CD20pos |</p>
<table>
<thead>
<tr>
<th>CD25high</th>
<th>CD25pos</th>
<th>T cell</th>
<th>T cell</th>
<th>B cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leukapheresis*</td>
<td>27.2 (1.9)</td>
<td>3 (3)</td>
<td>8 (8)</td>
<td>60 (1)</td>
</tr>
<tr>
<td>CliniMACS8/25</td>
<td>1.5 (0.0)</td>
<td>45 (19)</td>
<td>78 (0)</td>
<td>95 (1)</td>
</tr>
<tr>
<td>CliniMACS8/19/25</td>
<td>1.3 (0.1)</td>
<td>46 (13)</td>
<td>81 (5)</td>
<td>97 (1)</td>
</tr>
<tr>
<td>MiniMACS</td>
<td>-</td>
<td>88 (2)</td>
<td>90 (1)</td>
<td>98 (0)</td>
</tr>
</tbody>
</table>

N = 3.

*Partial leukapheresis products were used.

doi:10.1371/journal.pone.0003161.t001

### Table 2. Increase in CliniMACS Treg numbers by expansion.

<table>
<thead>
<tr>
<th>Polyclonal</th>
<th>Alloantigen</th>
</tr>
</thead>
<tbody>
<tr>
<td>CliniMACS8/25</td>
<td>31 (16)</td>
</tr>
<tr>
<td>CliniMACS8/19/25</td>
<td>34 (17)</td>
</tr>
<tr>
<td>MiniMACS</td>
<td>4 (0)</td>
</tr>
<tr>
<td>Tconv</td>
<td>46 (1)</td>
</tr>
</tbody>
</table>

Fold increase in cell numbers (SD) after 10 days expansion with indicated stimulus in the presence of exogenous IL-2, N = 3.

doi:10.1371/journal.pone.0003161.t002

The degree of purity of Treg that is required may depend on the actual application. In stem cell transplantation, the first clinical trials on Treg immunotherapy have recently been initiated. In these studies, either CliniMACS isolated CD4posCD25high Treg (with 40–60% purity) or \textit{ex vivo} manipulated CD4pos T cell lines consisting of 5–10% induced regulatory T1 cells and consequently a substantial amount of non-Treg were infused in patients receiving stem cell transplantations [24]. So far, to our knowledge, no adverse effects have been reported. However, caution is necessary when applying Treg for auto-immune disease or solid organ transplant purposes. Here an inadvertently present effector pool might cause serious pathology.

As cytotoxic CD8pos T cells are a potentially aggressive cell type in immune responses, it is highly recommendable to exclude these cells from CliniMACS isolated Treg populations. Here, we show that the CD8pos CliniMACS cell depletion step was effective: less than 0.1% CD8pos cells were present in isolated Treg populations, and no outgrowth of CD8pos cells occurred after expansion of CliniMACS Treg populations. Treg isolated by CD25pos enrichment following CD8pos depletion contained a small contamination of B cells (1–3%), which could increase to up to 10% after T cell expansion. The risks of infusion of expanded and activated autologous B cells are unknown, but could in theory include the development of a B cell lymphoproliferative disorder that can occur after transplantation and is often lethal [25–27]. We were able to prevent the contamination by B cells by including a CD19pos B cell depletion step in the isolation strategy.

Notwithstanding the favorable effects of combined anti-CD25, anti-CD8 and anti-CD19 microbead isolation (the currently available clinical grade tools), the isolated Treg population was of suboptimal purity. Most of the contaminating cells appeared to be CD4posCD25negpos Tconv cells that could potentially lead to immunopathology. To further improve CliniMACS Treg purity, Wichlan et al. studied titration of anti-CD25 microbeads in the enrichment phase of CliniMACS Treg isolation. While the use of lower amounts of beads indeed led to populations with higher CD25 expression levels [15], the suppressive capacity of the isolated populations did not improve and cell yields were significantly lower, indicating that titration of CD25 microbeads will not provide the solution to achieve higher purity for CliniMACS Treg isolation. These authors also reported that adjustment of CliniMACS flow rates did not lead to a higher Treg purity. Hoffmann et al. used three consecutive CliniMACS selection cycles for CD25pos cells, to preferentially select CD25high Treg and exclude CD25neg/low Tconv [14]. However, the degree of Treg purity obtained with this approach was similar to that achieved with one CD25 enrichment cycle.
Figure 2. Phenotypic and functional characteristics of expanded CliniMACS isolated Treg. Cell populations were expanded with polyclonal stimulus or alloantigen stimulus in the presence of exogenous IL-2. Data from a typical experiment are shown (N = 3). (A) Cell surface expression of CD25 and intracellular expression of FoxP3. (B) Proliferative capacity upon restimulation with allogeneic PBMC (same donor as in
Recently, it has been described that Tconv express the IL-7 receptor alpha chain CD127, while Treg do not express this molecule [22,23]. Thus, in the current study, we hypothesized that the conventional T cells contaminating GMP Treg populations could be excluded from the CliniMACS isolated populations by depleting CD127\(^{\text{pos}}\) cells. Since anti-CD127-microbeads for use in CliniMACS are currently not available, we depleted CD127\(^{\text{pos}}\) cells from CliniMACS isolated Treg populations by FACS. This procedure indeed increased Treg purity, as shown by uniformly high expression of FoxP3 in CD127\(^{\text{neg}}\) populations. After expansion of CliniMACS CD127\(^{\text{neg}}\) populations, high expression of FoxP3\(^{\text{neg}}\) was maintained, and the cell populations showed potent suppressive capacity. Notably, suppressive capacity of CliniMACS CD127\(^{\text{neg}}\) populations was significantly higher than that of non-depleted CliniMACS populations, indicating that CD127 depletion clearly enriched for functional Treg.

The outcome of a particular T cell based immune response is likely to be determined by the balance between the effector and regulatory T cell pools. Consequently, the efficacy of Treg therapy may be determined by the actual number of antigen reactive Treg within the infused cell population. Indeed, antigen-specific Treg were proven to be more efficient than polyclonal Treg within the infused cell population. Indeed, antigen-specific Treg were proven to be more efficient than polyclonal Treg within the infused cell population. Indeed, antigen-specific Treg were proven to be more efficient than polyclonal Treg within the infused cell population. Indeed, antigen-specific Treg were proven to be more efficient than polyclonal Treg within the infused cell population.

In summary, we here provide further support for clinical implementation of Treg immunotherapy by showing that a high Treg purity can be reached, and that isolated cells can be cryopreserved and expanded successfully.

**Materials and Methods**

**Human cells**

Healthy donors were scheduled for leukapheresis procedures to obtain leukocytes for donor lymphocyte infusions in hematopoietic stem cell transplantation patients in the Radboud University Nijmegen Medical Centre. Excess leukapheresis material was used for the current study upon written informed consent with regard to scientific use. Buffy coats from healthy human donors were purchased from Sanquin bloodbank, Nijmegen, The Netherlands, upon written informed consent with regard to scientific use and used as a source of stimulator PBMC. The current study did not require approval from an ethics committee according to the Dutch Medical Research Involving Human Subjects Act.

**Treg isolation**

Healthy donor leukapheresis products were used for CliniMACS CD4\(^{\text{pos}}\)/CD25\(^{\text{high}}\) Treg isolation. Cells were washed with PBS/EDTA buffer (Miltenyi Biotec, Bergisch-Gladbach, Germany, supplemented with 0.5% HSA (Sanquin bloodbank), Anti-CD8 and/or anti-CD19 coated CliniMACS microbeads (kindly provided by Miltenyi Biotec) were added, incubated for 30 minutes and washed. CliniMACS program 2.1 was run to deplete labeled cells (CliniMACS separation columns were kindly provided by Miltenyi Biotec). The labeling procedure was repeated with anti-CD25 CliniMACS microbeads, and CliniMACS program 1.1 was run to enrich for CD25\(^{\text{pos}}\) cells.

A non-GMP MiniMACS based CD4\(^{\text{pos}}\)/CD25\(^{\text{high}}\) Treg isolation method was performed on leukocytes from the same leukapheresis products as used for CliniMACS Treg isolation. PBMC were

![Figure 3. Cryopreservation of CliniMACS Treg affects suppressive capacity, which can be restored by activation.](image-url)
isolated by density gradient centrifugation (Lymphoprep, Nycomed Pharma, Roskilde, Denmark). CD4<sup>pos</sup> T cells were negatively selected using mAbs directed against CD8 (RPA-T8), CD14 (M5E2), CD16 (3G8), CD19 (4G7), CD33 (P67.6), CD235a (Ga-R2/HIR2) (BD Biosciences, San Jose, CA, USA), and CD56 (MOC-1) (Dako, Glostrup, Denmark) combined with sheep-anti-mouse-IgG coated magnetic beads (Dynal Biotech, Oslo, Norway), routinely resulting in a >90% pure CD4<sup>pos</sup> T cell fraction. CD25<sup>high</sup> Treg and CD25<sup>neg</sup> conventional T cells (referred to as T<sub>con</sub>, included in all experiments as control cell population) were separated by MACS-sorting, using 10 µl anti-CD25 magnetic microbeads/10<sup>7</sup> CD4<sup>pos</sup> cells (Miltenyi Biotec).

For CD127<sup>pos</sup> cell depletion, CliniMACS isolated Treg were stained with anti-CD127-AlexaFluor647 (BD Biosciences) and CD127<sup>pos</sup> cells were depleted on an Elite FACS machine (Beckman Coulter, Fullerton, CA, USA).

HLA typing was performed by serological and DNA based techniques according to international (ASHI/EFI) standards [28].

**Treg cryopreservation**

Treg cells were suspended in RPMI 1640 supplemented with pyruvate (0.02 mM), penicillin (100 U/ml), streptomycin (100 mg/ml), 20% human pooled serum (HPS) and 15% dimethylsulfoxide, were kept in −80°C for one week, and were subsequently transferred to liquid nitrogen for up to one year. Cells were quickly thawed in a 37°C water bath and washed twice before use.

**Treg expansion**

Cell cultures were performed in culture medium consisting of RPMI 1640 supplemented with pyruvate (0.02 mM), penicillin (100 U/ml), streptomycin (100 mg/ml), 10% HPS and IL-2 (25 U/ml, Chiron, Amsterdam, the Netherlands) with 5×10<sup>4</sup> cells per well in 96-well round bottom plates, in a 37°C, 95% humidity, 5% CO<sub>2</sub> incubator. Stimulation was provided by either 10<sup>5</sup> irradiated (30 Gy) fully HLA-mismatched allogeneic PBMC per
Figure 5. CliniMACS Treg isolation can be improved by depleting CD127\textsuperscript{pos} Tconv cells. CliniMACS populations were stained with anti-CD127 and sorted into CD127\textsuperscript{neg} and CD127\textsuperscript{pos} subsets. CliniMACS cells were cryopreserved prior to cell sorting. Data from one of two similar experiments are shown. (A) Cell surface expression of CD127, CD4 and CD25 and intracellular expression of FoxP3. (B-C-D) CliniMACS populations were expanded with alloantigen stimulation and exogenous IL-2. (B) Cell surface expression of CD25 and intracellular expression of FoxP3. (C)
well (alloantigen expansion) or 1×10⁴ anti-CD3+anti-CD28 mAb coated microbeads per well (Dynal Biotech, polyclonal expansion). Wells were split and provided with fresh medium containing cytokines every 3 days. After 10 days, the cells were harvested, washed and rested for 2 days in 5% HPS culture medium before functional and phenotypic analyses.

Flow cytometry

The phenotype of cells was analyzed by five-color flow cytometry (FC500, Beckman Coulter). For cell surface staining, the following conjugated mAbs were used: anti-CD45RA-FITC, anti-CD25-PE, anti-CD28-PE, and anti-CD95-APC (all from BD Biosciences). Fixation and permeabilization were performed using Fix/Perm buffer and anti-FoxP3(PCH101)-FITC was used according to the manufacturer’s instructions (eBioscience, San Diego, CA, USA). Isotype controls were used for gate settings.

Stimulation assay to analyze T cell anergy

T cell anergy was examined in (re-)stimulation assays. 2.5×10⁴ cells were stimulated with 10² irradiated allogeneic stimulator PBMC in the presence or absence of IL-2 (12.5 U/ml). Proliferation was measured at day 5 (primary response) or day 3 (secondary responses). To this end, 0.5 μCi [³H]Thymidine (Amersham Biosciences, Piscataway, NJ) was added to each well. After 8 hours, [³H]Thymidine incorporation was measured using a beta-plate counter (Packard, Canberra, Australia). Tests were set up in triplicate; results were expressed as mean±SD counts per 5 minutes.

Co-culture suppression assays

Suppressive capacity of Treg was studied in co-culture suppression assays. 5×10⁴ autologous responder T cells (CD4⁺CD25⁻, Tresp) were stimulated with 10⁵ irradiated allogeneic stimulator PBMC. Treg were titrated into these cultures. Proliferation was measured at day 5 by determination of [³H]Thymidine incorporation as described above. Tests were set up in triplicate, results were expressed as mean±SD counts per 5 minutes.

Statistical analysis

Proliferative capacities of different cell populations were compared using Student T tests. A P value<0.05 was considered statistically significant.

Supporting Information

Figure S1 Unaffected suppressive capacity of MiniMACS Treg by expansion prior to cryopreservation. Proliferative capacity of cryopreserved MiniMACS Treg isolated from healthy donor buffy coat in co-cultures of autologous naïve CD4⁺CD25⁻ Tresp stimulated with allogeneic PBMC. Data from one of two similar experiments are shown. Prior to co-culture suppression assay, indicated cell populations were expanded for 10 days in the presence of exogenous IL-2 and allogeneic PBMC (same donor as in co-culture suppression assay). Significant differences are indicated by asterisks. Open and filled asterisks refer to cryopreservation versus cryopreservation followed by expansion or expansion followed by cryopreservation, respectively. Found at: doi:10.1371/journal.pone.0003161.s001 (0.12 MB TIF)

Acknowledgments

We thank Paul Ruijs, Carel Trilsbeek and Jeroen van Velzen for excellent technical assistance.

Author Contributions

Conceived and designed the experiments: JHP HPBMK I. Performed the experiments: JHP RW. Analyzed the data: JHP HPBMK I. Wrote the paper: JHP FWP LBH HPBMK I.

References


