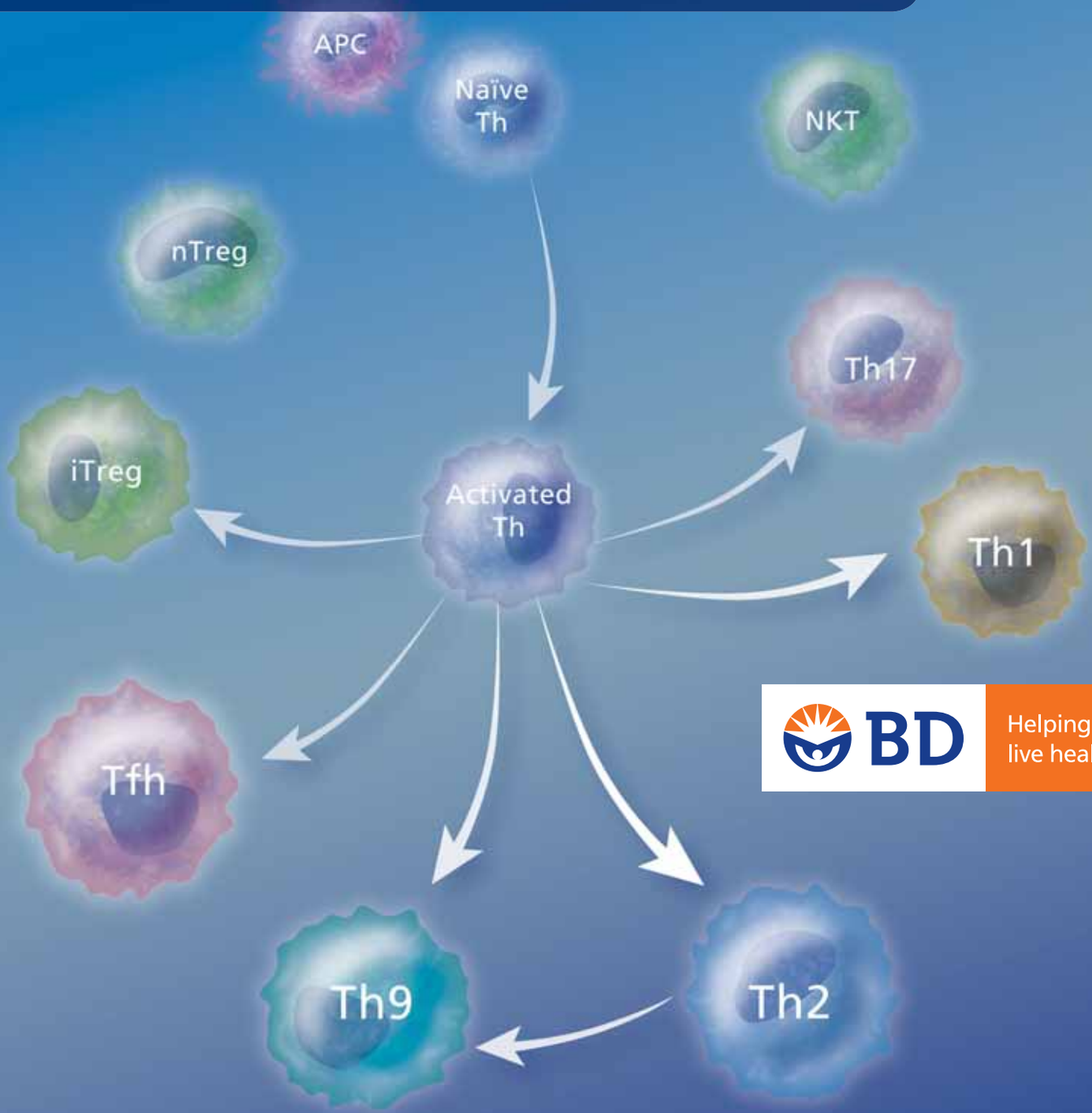
T-Cell Research

Novel multicolor flow cytometry tools for the study of CD4+ T-cell differentiation and plasticity



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A Solid Commitment to Research: Flexible Ways to Study CD4 T-Cell Differentiation and Plasticity

T cells have become a dynamic area of research. Among the methods used to characterize this major lymphocyte subset, multicolor flow cytometry is preeminent. Additionally, the complexity of the $CD3^+$ T-cell population—both functionally and phenotypically—makes multiparametric flow cytometry a necessary and powerful platform.

For more than two decades, researchers have made thousands of advances in T-cell study using BD flow cytometry products. And many of today's discoveries involving T cells also involve BD Biosciences platforms, reagents, instruments, and protocols.

BD continues to build on this commitment with new, quality reagents and kits, including IL-17F and T-bet monoclonal antibodies, Th17/Treg phenotyping kits, the Regulatory T Cell Sorting Kit, Th1/Th2/Th17 CBA kits, and the BD Phosflow™ T Cell Activation Kit.

T-cell subtypes can be defined by the combinations of cell surface markers and transcription factors they express and the cytokines they secrete. These proteins are regulated through signaling pathways. For example, the binding of IL-6 to its receptor leads to the phosphorylation of Stat3, which can then lead to the expression of IL-17A.

T-cell plasticity, the ability of a cell to change its phenotype in response to its environment, is of particular interest—especially for Th17 and regulatory T cells. This brochure discusses and demonstrates how the following platforms can be used to study T-cell differentiation:

Cell Surface Markers to identify cells from heterogenous samples

Intracellular Cytokine Staining (ICS) to measure cytokines within individual cells

BD Phosflow™ technology to measure the phosphorylation of key proteins

BD™ Cytometric Bead Array (CBA) to measure secreted cytokines within a sample

BD Biosciences continuously updates our portfolio of products for the analysis and enrichment of T cells. BD Biosciences reagents are backed by a world-class service and support organization to help customers take full advantage of our products to advance their research. Comprehensive services include technical application support and customer assay services provided by experienced scientific and technical experts.

A dynamic area of research

T Cells: An Overview

Summary of T-cell Subsets

T cells can be separated into three major groups based on function: cytotoxic T cells, helper T cells (Th), and regulatory T cells (Tregs). Differential expression of markers on the cell surface, as well as their distinct cytokine secretion profiles, provide valuable clues to the diverse nature and function of T cells.[1]

For example, $CD8^+$ cytotoxic T cells destroy infected target cells through the release of perforin, granzymes, and granulysin, whereas $CD4^+$ T helper cells (ie, Th1, Th2, Th9, Th17, and Tfh cells) have little cytotoxic activity and secrete cytokines that act on other leucocytes such as B cells, macrophages, eosinophils, or neutrophils to clear pathogens. Tregs suppress T-cell function by several mechanisms including binding to effector T-cell subsets and preventing secretion of their cytokines.

To support the use of multicolor flow cytometry for the study of T cells, BD offers a deep portfolio of reagents, which are highlighted in red in the table below. BD now also offers more choice. Many of these specificities are available in multiple formats including BD Horizon™ V450 and V500 formats for use with the violet laser.

Tregs: Essential Regulators of Immunity

Tregs play an important role in maintaining immune homeostasis and have also been implicated in a number of autoimmune diseases.[4] Flow cytometry is a particularly useful application for the sorting and analysis of Tregs.

Two major classes of $CD4^+$ Tregs have been identified to date: "natural" Tregs (nTregs) that constitutively express CD25 and FoxP3, and adaptive or inducible Tregs (iTregs) in which CD25 and FoxP3 expression is activated.[5] CD25 expression differs between human and mouse Tregs. In mice all $CD25^+$ cells are considered Tregs, compared to humans, for whom only those cells expressing the highest levels of CD25 are considered to be Tregs.[6]

Type of Cell	Cytotoxic	Th1	Th2	Th9[2]	Th17	Tfh[3]	Treg
Main Function	Kill virus-infected cells	Activate microbicidal function of infected macrophages, and help B cells to produce antibody	Help B cells and switch antibody isotype production	T cell proliferation and enhanced IgG and IgE production by B cells	Enhance neutrophil response	Regulate development of antigen specific B cell development and antibody production	Immune regulation
Pathogens Targeted	Viruses and some intracellular bacteria	Intracellular pathogens	Parasites	Parasites	Fungi and extracellular bacteria		
Harmful Function	Transplant rejection	Autoimmune disease	Allergy, asthma	Allergy	Organ-specific autoimmune disease	Autoimmune disease	Autoimmune disease, cancer
Extracellular Markers	CD8	CD4 CXCR3	CD4 CCR4, Crth2 (human)	CD4	CD4, CCR6	CD4, CXCR5	CD4, CD25
Differentiation Cytokines		IFN-γ, IL-2, IL-12, IL-18, IL-27	IL-4, IL-2, IL-33	IL-4, TGF-β	TGF-β, IL-6, IL-1, IL-21, IL-23	IL-12, IL-6	TGF-β, IL-12
Effector Cytokines	IFN-γ, TNF, LT-α	**IFN-γ**, LT-α, TNF	**IL-4,** IL-5, IL-6, IL-13	IL-9, IL-10	**IL-17A,** IL-17F, IL-21, IL-22, IL-26, TNF, CCL20	IL-21	TGF-β, IL-10
Transcription Factors		T-bet, Stat1, Stat6	GATA3, Stat5, Stat6	GATA3, Smads, Stat6	RORγt, RORα, Stat3	Bcl-6, MAF	FoxP3, Smad3, Stat5

This table summarizes major known T-cell markers.

Markers can be altered as a result of cellular environment, differentiation state, and other factors. Key cytokines appear in **bold**. BD Biosciences offers reagents for molecules in red.

Adaptive or inducible Tregs originate from the thymus as single-positive CD4 cells. They differentiate into CD25 and FoxP3 expressing Tregs following adequate antigenic stimulation in the presence of cognate antigen and specialized immunoregulatory cytokines such as TGF-β, IL-10, and IL-2. The iTreg population is also reported to be more plastic, with the ability to convert to other T-cell subtypes such as Th1 and Th17 cells.[7]

FoxP3 is currently the most definitive marker for Tregs, although there have been reports of small populations of FoxP3$^-$ Tregs. The discovery of the transcription factor FoxP3 as a marker for Tregs has allowed scientists to better define these populations, leading to the discovery of additional Treg markers, including CD127. Several published reports in addition to data generated at BD have demonstrated that CD127 expression is inversely correlated with FoxP3.[6,8] The sorting strategy of collecting CD4$^+$, CD25$^+$, and CD127$^-$ cells is useful for obtaining viable, expandable Tregs.

Enrichment of Tregs

Studies by Miyara[9,10] and Hoffmann[11] have found that CD45RA is a useful marker to identify and isolate naïve Treg subpopulations. CD45RA$^+$ Tregs may be less plastic, maintaining FoxP3 status, post-expansion. CD45RA antibodies are an optimized drop-in in BD Biosciences new sorting kit.

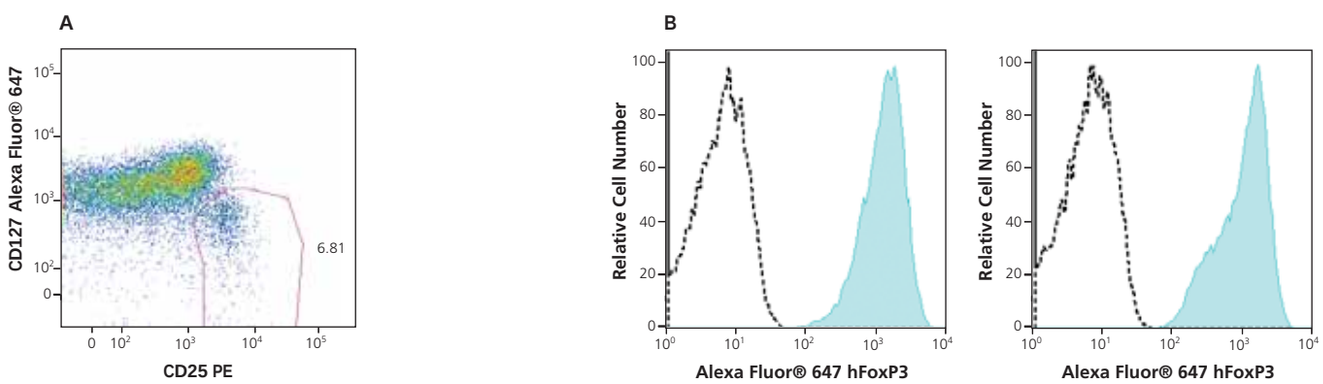
In the experiment below, the CD45RA$^+$ Treg subpopulation (left histogram, solid blue) showed no tendency to lose its FoxP3 expression. However, unexpectedly, the CD45RA$^-$ Treg subpopulation (right histogram) did show reduced expression of FoxP3 in some cells. Further research is needed to explore these Treg subsets.

Four-color analysis of the expression of CD4, CD25, CD127, and CD45RA on sorted peripheral blood mononuclear cells (PBMCs).

PBMCs were stained with the BD™ Human Regulatory T Cell Sorting Kit (Cat. No. 560753) and then sorted on a BD FACSAria™ cell sorter. Lymphocytes were identified by light scatter profile and CD4$^+$ expression and sorted for CD4 Treg profile (panel A). The CD45RA negative and positive fractions (data not shown) were sorted, then separately expanded. Fractions were stained with isotype control (Cat. No. 557732) and conjugated anti-human FoxP3 monoclonal antibody (Cat. No. 560045).

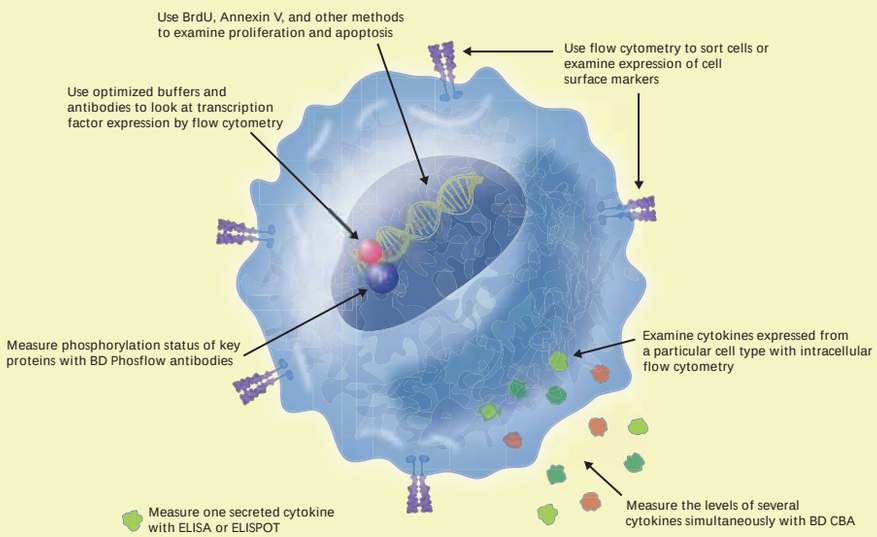
A Data representing the CD25 and CD127 expression profile of the CD4 positive cells prior to gating on CD45RA populations for sorting.

B Data showing hFoxP3 expression on sorted CD25^{high} CD127^{low} Tregs (blue solid histogram) and isotype control (dashed line) for the CD45RA$^+$ and CD45RA$^-$ fractions, respectively. Acquisition and analysis were performed on a BD™ LSR II system.



Leading tools to support and streamline T-cell research

Tools and Techniques for T-cell Analysis



A variety of tools from BD allow the detailed study of cell populations.

BD products facilitate the detection of cell surface markers, phosphorylated proteins, transcription factors, apoptosis markers, and cytokines. Secreted cytokines can be measured with ELISA or ELISPOT for single cytokines or by BD CBA for multiplexed assays to measure several cytokines in the same well. Using these techniques, researchers can learn the percentage of a certain type of cell along with its activation status, allowing the effect of minute changes (in protein phosphorylation status, cytokine levels, etc) to be determined within populations of cells.

Donor variability caused by factors such as differences in age or antigen exposure can contribute significantly to heterogeneity in peripheral lymphoid cell populations, including those found in peripheral blood.

BD's comprehensive portfolio of reagents includes products for surface marker analysis for phenotyping cells, and for intracellular flow cytometry for detecting effector molecules (such as cytokines and chemokines) and cell signaling molecules (such as transcription factors and phosphorylated proteins).

BD also provides optimized buffers, fluorescent antibody cocktails, and kits combining surface staining with intracellular flow cytometry to enable researchers to maximize the information obtained from analysis of individual samples.

Tool/Technology	Flow Cytometry/Surface	Flow Cytometry/Intracellular	BD Cytometric Bead Array (CBA)	ELISPOT	ELISA	In Vivo Capture Assay
Molecules detected	Surface	Intracellular and surface	Secreted or intracellular	Secreted (in situ)	Secreted	Secreted (in vivo)
Multiparameter	Yes	Yes	Yes	No	No	No
Single cell/cell subset information	Yes	Yes	No	Frequencies, no subset information	No	No
Antigen specific	Yes	Yes	Yes	Yes	Yes	Yes
Post-assay viability	Yes	No	Yes, for secreted molecules	No	Yes	Yes
Quantitation of protein	Possible*	Possible*	Yes	No	Yes	Yes
Instrumentation	Flow cytometer	Flow cytometer	Flow cytometer	ELISPOT reader	Spectrophotometer	Spectrophotometer

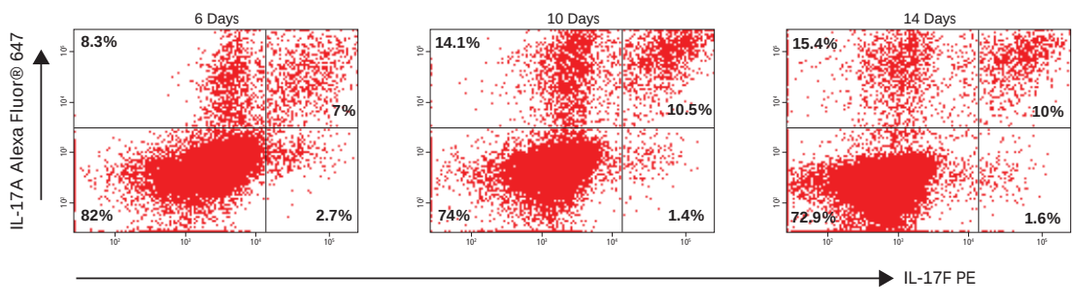
**With a standard such as BD Quantibrite™ beads*

Phenotyping of Cells with Unique Surface Marker Profiles
T cells and their subsets can be defined by differential expression of cell surface markers, including CD3, CD4, CD8, and CD25. Adding markers such as CCR7, CD62L, or CD69 to an analysis provides important information about the potential for cells to home and localize within the body, as well as the activation status of the T-cell subset of interest.

Cell surface markers can also be used with cell sorters, such as the BD FACSAria™ III and BD Influx™ systems. Purified, viable cell populations can be expanded, differentiated, and maintained in culture.

Intracellular Flow Cytometry
Intracellular flow cytometry, especially when combined with cell surface staining, is a powerful tool for the detection of cytokines and transcription factors from both homogenous and mixed cell populations. For intracellular protein detection, cells must be fixed and permeabilized to allow a fluorescent antibody to enter and detect the target protein of interest. Different antigens have different sensitivities to and requirements for fixation and permeabilization, requiring additional optimization of protocols. To detect cytokines, which are secreted proteins, protein transport inhibitors such as BD GolgiStop™ (monensin) or BD GolgiPlug™ (brefeldin A) inhibitors are used to trap proteins inside the cell.

BD Biosciences offers two different reagent systems, BD FastImmune™ and BD Cytofix/Cytoperm™, that have been optimized for intracellular cytokine staining. BD FastImmune kits are complete, optimized systems for the detection of cytokines, cell surface markers, and other molecules from human whole blood and PBMC samples. To maximize flexibility and quality of results, BD Cytofix/Cytoperm buffer systems and protocols allow researchers to design flow cytometry experiments such as the comparison of IL-17A and IL-17F shown below.



IL-17A and IL-17F staining using a BD Cytofix/Cytoperm protocol.

IL-17A and IL-17F are both members of the IL-17 cytokine family. While both are believed to be involved in inflammatory responses, IL-17A and IL-17F are expressed in separate but overlapping T-cell populations.[12] Human cells polarized toward a Th17 phenotype were characterized for IL-17A and IL-17F expression, using the BD Cytofix/Cytoperm™ protocol. Cells were cultured in the presence of Th17-polarizing cytokines and with a protein transport inhibitor, such as BD GolgiStop (monensin) or BD GolgiPlug (brefeldin A) to prevent secretion and thus allow accumulation of the cytokine inside the cell. Cells were fixed and permeabilized with BD Cytofix/Cytoperm fixation/permeabilization solution to allow fluorescent antibodies to enter the cell and bind to their target cytokines. Cells were then stained with antibodies to CD4, IL-17A, and IL-17F and then detected by multicolor flow cytometry.

Obtain the complete picture

Techniques for the Detection of Secreted Cytokines

Detection of cytokines on an intracellular level provides one useful set of data. To obtain a more complete picture of T-cell cytokine profiles, it is also helpful to quantitate cytokines secreted into the medium.

Cytokines from cell populations can be quantified by techniques such as BD Cytometric Bead Array (CBA) and ELISA. BD CBA can simultaneously quantify multiple cytokines from the same sample, while ELISA is a useful assay for measuring levels of single cytokines.

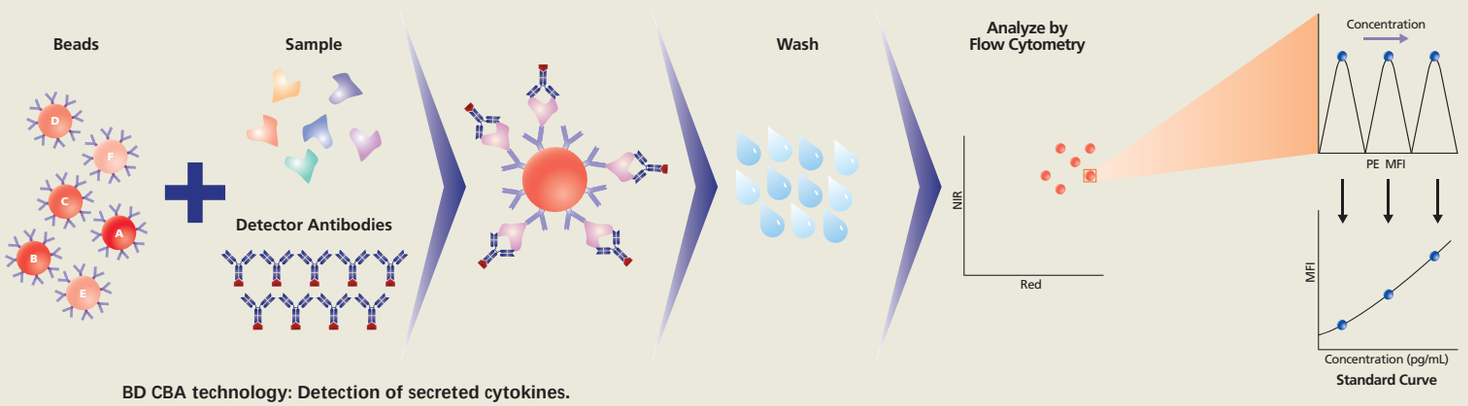
CAPABILITY	BD CBA	ELISA	ICS
Allows detection of multiple cytokines in same experiment	✓		✓
Can obtain phenotype of specific cells expressing cytokine of interest			✓
Can measure quantity of cytokine secreted	✓	✓	

Comparison of BD CBA vs BD ICS for the study of cytokine secretion

BD CBA is a flow cytometry application that allows users to quantify multiple proteins simultaneously. The BD CBA system uses the broad dynamic range of fluorescence detection offered by flow cytometry and antibody-coated beads to efficiently capture analytes. Each bead in the array has a unique fluorescence intensity so that beads can be mixed and run simultaneously in a single tube. This method significantly reduces sample requirements and time to results in comparison with traditional ELISA and Western blot techniques.

Combining BD CBA and the BD Cytofix/Cytoperm System to Determine Th1/Th2/Th17 Cytokine Profiles

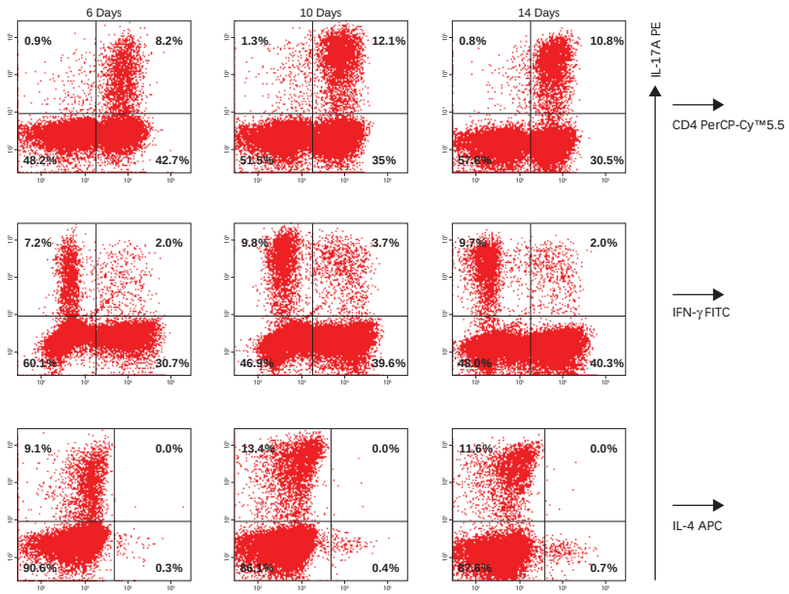
Both BD CBA and intracellular flow cytometry techniques reveal useful information about a sample. The strength of intracellular flow cytometry is its ability to determine the number and phenotype of cells expressing a cytokine from a heterogenous population. The advantage of BD CBA is the ability to quantitate the levels of multiple cytokines simultaneously. Since BD CBA detects secreted cytokines in the medium surrounding the cells, the cells can be used for additional experiments. This makes the two methods complementary to one another.



BD CBA technology: Detection of secreted cytokines.

BD CBA products, designed for easy and efficient multiplexing, require no assay formulation regardless of plex size. The products deliver quantitative results from a single small-volume sample, and require less time, compared with competitive bead-based immunoassays.

Time Course Study of Th17 Cell Population



Representative data from Th17 polarized cell ICS experiments comparing levels of IL-17A with CD4, IFN-γ, and IL-4.

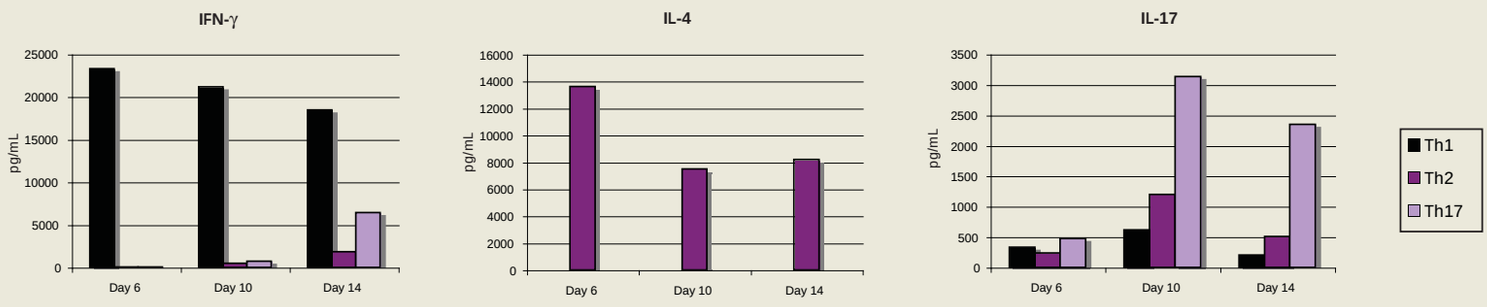
Cells were treated under the Th17 polarizing conditions described for the indicated time points. They were treated with BD GolgiStop (monensin) inhibitor, fixed and permeabilized with BD Cytofix/Cytoperm buffer, and then stained with antibodies against the indicated cytokines. At 6 days there were significant numbers of cells expressing IL-17A, with numbers of cells increasing at day 10 and then leveling off.

Combining BD CBA and Intracellular Flow Cytometry to Examine Th17-cell Differentiation

With both BD CBA and intracellular cytokine staining (ICS) available, scientists at BD performed an experiment to examine T-cell differentiation, which can be induced by activation and treatment with cytokines. To study Th1/Th2/Th17-cell differentiation, $CD4^+$-panned human T cells isolated from normal donors were co-stimulated with CD3/CD28 and:

- IL-2, IL-12, and a neutralizing mAb to IL-4 (Th1 polarization)
- IL-2, IL-4, and a neutralizing mAb to IFN-γ (Th2 polarization)
- IL-2, IL-6, IL-1β, TGF-β, IL-23, and neutralizing mAb to IL-4 and IFN-γ (also tested with and without IL-2, IL-6, and TGF-β) (Th17 polarization)

Samples from whole cells and supernatant were collected at the time points indicated, stimulated with PMA/ionomycin, and analyzed by ICS and BD CBA. Data from the Th17 polarization is shown as an example of ICS, and all three conditions are shown for BD CBA. Combining these techniques, similar trends were observed when comparing the increase in number of cells expressing the cytokine to the total amount of secreted cytokines.

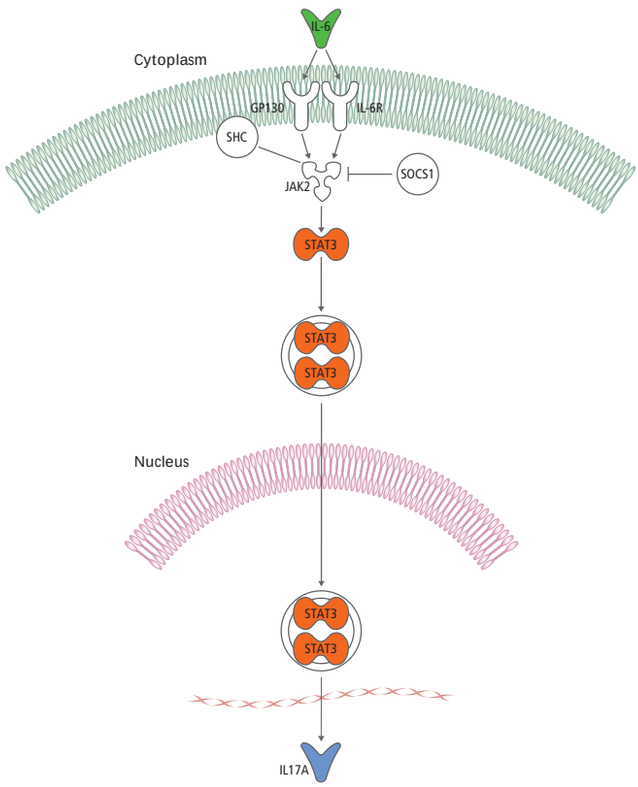


Data comparing cytokine levels as a result of different polarization conditions.

Supernatants from cells were polarized toward a Th1, Th2, or Th17 phenotype and cytokine levels were measured by BD CBA. As anticipated, each polarized condition resulted in the production of the signature cytokine associated with each Th cell type.

The importance of phosphoprotein detection

Tools for Analysis of T-cell Signaling



BD Cell Pathways tool

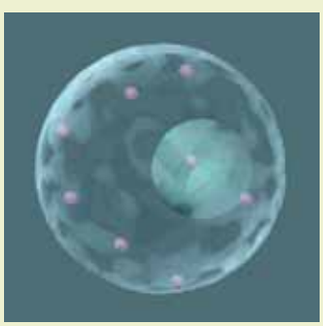
To support signaling research, the BD Biosciences website includes the BD Cell Pathways tool, powered by Ingenuity Systems, to help researchers explore the pathways that involve target molecules of interest. This image (adapted from Ingenuity) illustrates the mechanisms leading to the commitment of CD4 T cells to Th17 cell lineage.

T cells are activated and regulated by complex pathways involving a number of signal transduction molecules, including receptors for antigens and cytokines, kinases, and transcription factors. When foreign antigens enter the body, they are recognized by the innate immune system, which in turn responds with the expression of surface co-stimulatory molecules and the release of cytokines.

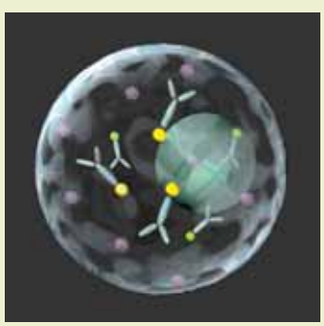
These expressed molecules inform the adaptive immune system about the type and strength of the offending pathogen. As a result, naïve $CD4^+$ T cells differentiate into Th1, Th2, Th9, Th17, Tfh, or Treg cells.

T-cell differentiation can be mediated by protein phosphorylation. Different cytokines bind to their cognate receptors expressed by naïve T cells, which leads to the phosphorylation and dimerization of activating proteins, including Signal Transducers and Activator of Transcription (Stat) proteins.[6,13] Upon phosphorylation and dimerization, activated Stat proteins enter the nucleus and bind to the promoters of many different genes, resulting in the expression of other transcription factors and cytokines specific to a particular T-cell phenotype.

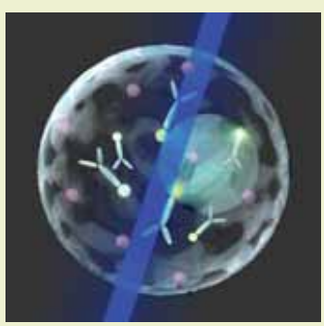
Step 1: Fix cells with one of the BD Phosflow fixation buffers.



Step 2: Permeabilize cells with one of the BD Phosflow permeabilization buffers.



Step 3: Stain cells with directly conjugated BD Phosflow antibodies in BD Pharmingen™ stain buffer.



Step 4: Analyze cells on a BD FACS™ Instrument.

BD Phosflow Technology: Detecting Transient Phosphorylation Events

Innovative BD Phosflow technology is the first complete flow cytometry solution to reveal intracellular data on basal and induced protein phosphorylation events in both cell lines and primary cells. The BD Phosflow approach is especially informative with T cells, in which phosphorylation of signaling pathway proteins—such as Stat transcription factors—leads to the expression of particular T-cell phenotypes.

BD Biosciences provides reagents and kits for the study of protein phosphorylation by flow cytometry, including the BD Phosflow T Cell Activation Kit, as well as BD Phosflow antibodies such as anti-Stat3 (pY705).

Specialized Antibodies and Buffers

Developed collaboratively by BD and researchers at Stanford University, BD Phosflow technology consists of phosphoprotein-specific, fluorochrome-labeled, monoclonal antibodies, along with a system of optimized buffers. These buffers fix the cellular proteins to maintain their phosphorylation state, and then permeabilize the cell membrane to allow the antibodies to be introduced. Flow cytometry can then capture an intracellular snapshot of protein phosphorylation events.

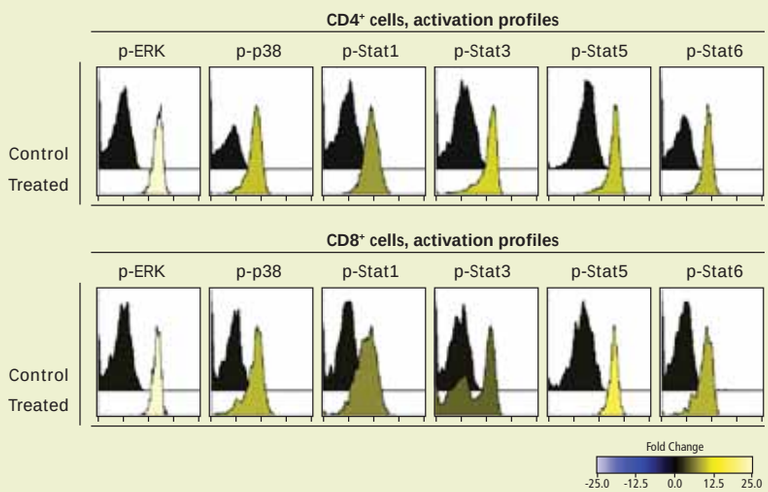
Used in combination with cell surface markers, BD Phosflow technology can evaluate phosphoprotein activation from populations within heterogenous samples, such as whole blood. It is an ideal solution when removal of red blood cells may unintentionally activate stress-induced signaling (p38/MAPK) pathways. Even rare cell subtypes can be identified without upfront enrichment.

T-cell activation profiles monitored with the BD Phosflow T Cell Activation Kit

The BD Phosflow T Cell Activation Kit is a comprehensive research system that uses flow cytometry to reliably determine the level of key phosphorylated signaling proteins involved in T-cell activation. The ready-to-use kit includes pre-titrated fluorochrome-conjugated antibodies, optimized buffers, experiment setup beads, lyophilized human control cells, validated protocols, and access to Cytobank software for storing, sharing, and analysis of data. The kit offers a total solutions approach that minimizes assay-to-assay variability to help both experienced and novice flow cytometry users produce more dependable, comparable results faster.

The histogram overlays below (using Cytobank software) show $CD4^+$ and $CD8^+$ T-cell signaling responses to treatment, monitored using the BD Phosflow T Cell Activation Kit. Response modifiers are described in the chart to the left.

Activator (response modifier)	Phosphorylation marker
PMA	ERK 1/2, p38MAPK
hIFN-α	Stat1
hIL-6	Stat3
hIL-2	Stat5
hIL-4	Stat6



The importance of differentiation

Tools for Measuring Treg/Th17 Plasticity

The differentiation of naïve T cells into unique subsets was once thought to be irreversible. In the last few years, published reports have demonstrated plasticity among different T-cell subtypes, particularly Tregs and Th17 cells.

Because flow cytometry can look inside the cell, it is well suited to study T-cell plasticity. The data on these two pages shows how ICS, BD CBA, and BD Phosflow technology together can paint a detailed picture of the mechanisms contributing to Treg/Th17 plasticity.

Treg and Th17 Differentiation Mechanisms

Both Tregs and Th17 cells require TGF-β for induction. Mice lacking TGF-β do not have Foxp3$^+$ Tregs or IL-17 cells, resulting in severe autoimmunity.[14] When antigen activated, naïve T cells are exposed to TGF-β, and the key transcription factors, Foxp3 for Tregs and RORγT for Th17, are both expressed. These cells produce less IL-17 compared to cells that do not express Foxp3. One proposed mechanism is that Foxp3 antagonizes IL-17 production induced by RORγT. Direct intermolecular interactions between a motif on exon 2 of Foxp3 and a conserved domain of both RORα and RORγT have been demonstrated.[15]

The amount of TGF-β present in combination with other cytokines in the local milieu can influence T-cell fate. High levels of TGF-β tend to favor Treg differentiation while lower levels of TGF-β in combination with proinflammatory cytokines (eg, IL-1, IL-6) favor Th17 differentiation.[16] These proinflammatory cytokines act through Stat3. Forced expression of the activated form of Stat3 leads to enhanced activation of IL-17. Stat5 is important for Treg development.

Experimental Design

To illustrate the utility of BD products for the study of Treg/Th17 plasticity, an experiment was performed using intracellular flow cytometry, BD CBA, and BD Phosflow markers for Th17 and Tregs. CD4$^+$-enriched mouse splenocytes were activated with anti-CD3/CD28 and polarized toward a Th17 phenotype by treating them with cytokines as illustrated on the next page. While it is possible to detect Tregs and Th17 cells in the same tube, under these experimental conditions cell polarization toward a Th17 phenotype was observed. Cells co-expressing both Foxp3 and IL-17A were not observed.

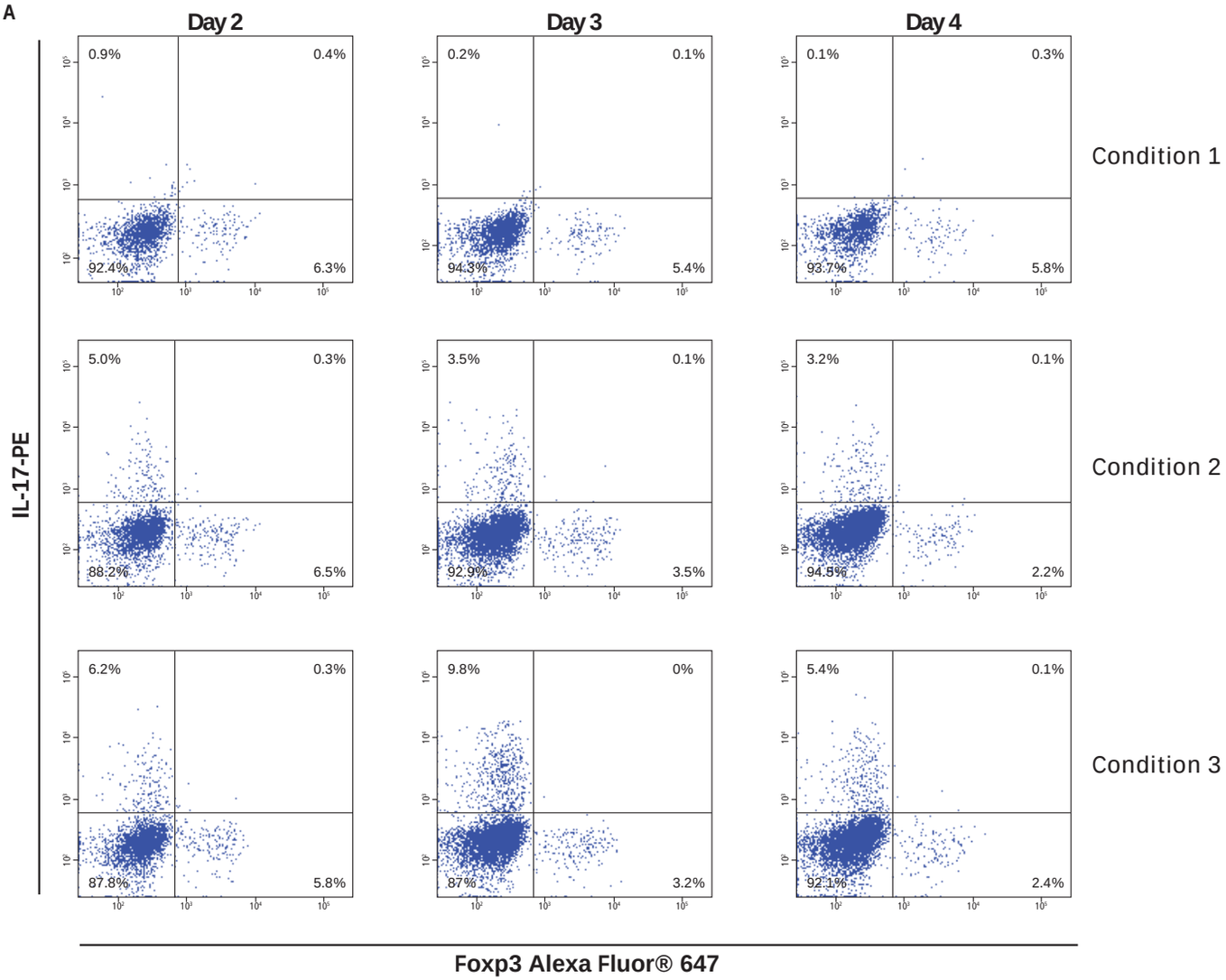
Comparable studies of Treg/Th17 plasticity

A Cells were cultured under the indicated conditions and times, then treated with BD GolgiStop (monensin) inhibitor prior to fixation and permeabilization with mouse Foxp3 buffer. Cells were stained with CD4, IL-17A, and Foxp3. Data is shown starting from day 2.

B Shows data from the measurement of IL-17A by BD CBA from cell supernatants from the indicated culture conditions and time points. No protein transport inhibitor was added to allow secretion of cytokines.

C Samples were treated as indicated. On day 4 cells were stimulated with PMA/Ionomycin, and phosphorylated Stat5 was measured with BD Phosflow technology using BD Phosflow permeabilization buffer III. Flow cytometry was performed on a BD LSR II system. Data was analyzed with Cytobank software, a partner of BD (cytobank.org). No protein transport inhibitor was added to measure the effects of secreted cytokines.

A

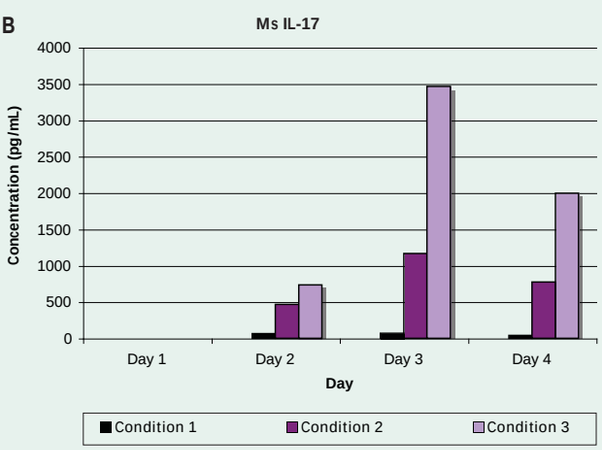


Condition 1: Anti-CD3/CD28 only

Condition 2: Anti-CD3/CD28, IL-1β, IL-6, and TGF-β

Condition 3: Anti-CD3/CD28, IL-1β, IL-6, TGF-β, and IL-23

B



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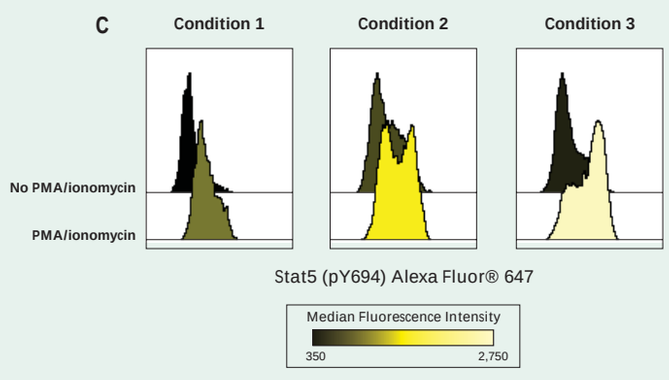

Service and Support

BD Biosciences instruments and reagents are backed by a world-class service and support organization with unmatched flow cytometry experience. For more than 20 years, BD has actively worked with T-cell researchers to develop tools that help improve workflow, ease of use, and performance.

Researchers come to BD Biosciences not only for quality products, but as a trusted lab partner. Our repository of in-depth, up-to-date knowledge and experience is available to customers through comprehensive training, application and technical support, and expert field service.

For example, our website, bdbiosciences.com, now incorporates BD Cell Pathways, a collection of detailed, interconnected, interactive maps of biological signaling and metabolic pathways. Researchers can look up specific genes or molecules in the knowledge database, trace the pathways that involve them, and find BD products related to them.

Technical Applications Support

BD Biosciences technical applications support specialists are available to provide field- or phone-based assistance and advice. Expert in a diverse array of topics, BD technical application specialists are well equipped to address customer needs in both instrument and applications support.

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