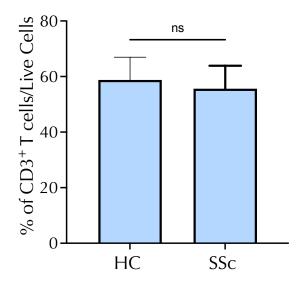
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CD57 HCD57 142Nd CD123 6H6 143Nd GraB GB11 144Nd CRTH2 BM16 145Nd CD8a RPA T8 146Nd CD45RO UCHL1 147Sm CD28 CD28.2 148Nd Grak GM26E7 149Sm CD11c Bu15 150Nd ICOS C398.4A 151Eu CD14 M5E2 152Sm CCR2 K036C2 153Eu TIGIT MBSA43 154Sm CD4 RPA T4 155Gd CD73 AD2 156Gd CD73 AD2 156Gd CD16 3G8 157Gd CD27 L128 158Gd CCR7 G043H7 159Tb CXCR6 K041E5 160Gd T-bet 4B10 161Dy FoxP3 PCH101 162Dy CXCR3 G025H7 163Dy CXCR5	CD3	UCHT1	115In
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CCR2 K036C2 153Eu TIGIT MBSA43 154Sm CD4 RPA T4 155Gd CD73 AD2 156Gd CD16 3G8 157Gd CD27 L128 158Gd CCR7 G043H7 159Tb CXCR6 K041E5 160Gd T-bet 4B10 161Dy FoxP3 PCH101 162Dy CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56	ICOS	C398.4A	151Eu
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CCR7 G043H7 159Tb CXCR6 K041E5 160Gd T-bet 4B10 161Dy FoxP3 PCH101 162Dy CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CD16	3G8	157Gd
CXCR6 K041E5 160Gd T-bet 4B10 161Dy FoxP3 PCH101 162Dy CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CD27	L128	158Gd
T-bet 4B10 161Dy FoxP3 PCH101 162Dy CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CCR7	G043H7	159Tb
FoxP3 PCH101 162Dy CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CXCR6	K041E5	160Gd
CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	T-bet	4B10	161Dy
CXCR3 G025H7 163Dy CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	FoxP3	PCH101	162Dy
CXCR5 J252D4 164Dy CD127 TX31 165Ho GATA3 TWAJ 166Er CD38 HTA125 167Er CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CXCR3	G025H7	
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CCR9 L053E8 168Er TCRgd B1 169Tm CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	GATA3	TWAJ	166Er
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CX3CR1 2A9-1 170Er CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CCR9	L053E8	168Er
CCR5 NP6G4 171Yb Ki67 B56 172Yb CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	TCRgd	B1	169Tm
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CD25 M-A251 173Yb CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CCR5	NP6G4	171Yb
CCR10 6588-5 174Yb PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	Ki67	B56	172Yb
PD-1 EH12.2H7 175Lu CD56 R19760 176Yb	CD25	M-A251	173Yb
CD56 R19760 176Yb	CCR10	6588-5	174Yb
	PD-1	EH12.2H7	175Lu
HLA-DR BVD2-23B6 209Bi	CD56	R19760	176Yb
11EA DI	HLA-DR	BVD2-23B6	209Bi

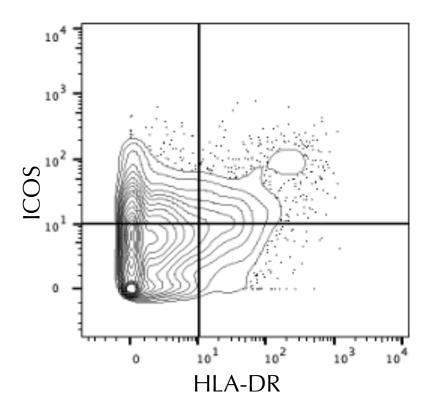
Supplementary Table 1: Markers used for mass cytometry analyses.

Signature	Genes
Cytotoxicity	GZMA, GZMB, GZMH, PRF1, NKG7, GNLY, CD40LG, KLRG1, KLRB1, ITGAL
Tfh	CXCR5, CXCL13, TOX2, ICA1, PDCD1, FAM43A, SCGB3A1, ASCL2, CHI3L2, CDK5R1, CEBPA, GNG4, CXXC5, GFOD1, TIGIT, POU2AF1, ATP9A, KIAA1671, SGPP2, BCL6, EGR2, LGMN, CD79A, KIAA1324, NFATC1, MYL6B, BCAT1, CTLA4, KCNK5, CTTN, LAG3, ICOS, THADA, LHFPL2, MAF, ID3, TRIB1, BTLA, SLC9A9, CAV1, SH2D1A, SH3TC1, MAGEH1, ST8SIA1, IKXF3, IGFBP4, NMB, TBC1D4, TRIM8, CCDC50, MYH10, PTPN11, FAM46C, ITM2A, FABP5, SPSB1, ODC1, MERTK, FBLN7, SERTAD2, TOX, CORO1B, SCD, SHISA2, RAB27A, FAM167A, STX11, LRRC1, PTTG1, CD200, KIAA0101, LIMS1, SLC7A5, PON2, FKBP5, NAB1, PFKFB3, DUSP6, AIM2, GADD45G, COL6A3, FAM179A, PHGDH, NUDT7, RNF19A, DUSP2, PAQR4, PPP1CC, SLC25A46, CARHSP1, HES6, H1F0, SRGN, CDCA7, SIRPP6, MT1E, CD38, ASB2, KIFC1, RDH10, LRMP, DDIT4, P2RY11, NUCB2, TMEM2, ACTA2, SERPINE2, CASP9, INPP1, SGCE, MTUS1, GRAMD3, AFF3, NCALD, ANKRD55, AGMAT, TRIM32, CPA5, MAPK6, NDFIP2, UBE2E3, SEPN1, LIMS2, NETO2, GLCCI1, FAAH2, RPL39L, SSH2, PHACTR2, ERMP1, TNFRSF18, ANKS1B, SOCS1, FEN1, PYHIN1, PTPN13, QPRT, ACTN1, MYO5A, POMT1, LAT, SYYT11, BCAS4, INSIG1, WSB2, RB11FIP1, NR3C1, TRAF3IP2, GINS2, RFC5, FAM110A, RILPL2, IL2RB, ASAP1, GK, TSPAN5, ALDH5A1, TIAM1, CBLB, CLINT1, SMPDL3A, SIPA1L2, JARID2, ORMDL3, TSHR, BAZ2B, ATP6V1D, ZFPM1, TM2D3, RAB37, GPR19, F2R, SRPK2, BIK, FBXO33, MAPKAPK3, PTPN2, LBH, PTPN7, UBE2G1, FHL2, TJP2, IFNAR2, VOPP1, IRF4, CDK6, HIF1A, P2RX5, CXCR4, TMEM99, FYN, DCUN1D3, BATF, CDT1, GF11, ARHGAP10, PRKCZ, IL6R, LTA, KPNA2, PPP2RSC, PPP1R16B, VWA5A, FAM160B1, TMEM64, MBOAT1, FAM134B, TP531NP1, RYR1, AKAP13, PCNA, HIST1H2BD, HES4, NAP1L4, PLCH2, GAPDH, HECW2, TRIB2, SAT1, SLC29A1, ZFP91, RACGAP1, MCM2, SFXN1, IL21

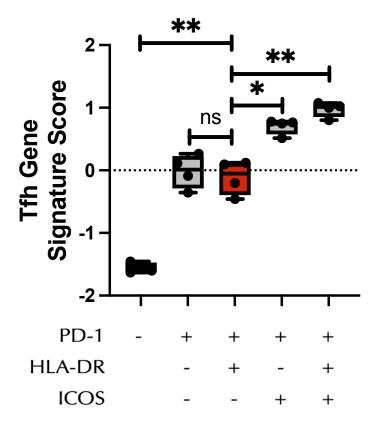
Supplementary Table 2: Genes used for Cytotoxicity and Tfh Gene Enrichment Scores. Genes comprising the cytotoxicity and Tfh gene signatures were derived from Hashimoto *et al.* 2019 and Locci *et al.* 2013, respectively.



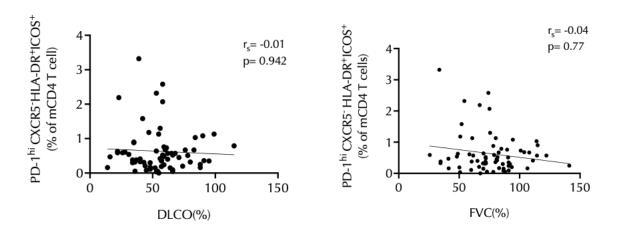
Supplementary Figure 1: Percentage of total T cells are similar in healthy controls and SSc patients. Quantification of CD3+ T cells in patients with SSc (n = 82) compared with healthy controls (n = 18) using mass cytometry data. ns, non-significant.



Supplementary Figure 2. ICOS expression is a continuum in PD-1hi CXCR5- HLA-DR+ CD4 T cells. Biaxial plot of ICOS expression in PD-1hi CXCR5- CD4 T cells.



Supplementary Figure 3: PD-1^{hi}CXCR5⁻HLA-DR⁺ICOS⁻ CD4 T cells show a lower Tfh score associated with a T helper phenotype compared with other PD-1^{hi}CXCR5⁻ CD4 T cell populations. The Tfh gene signature score is depicted for the CD4 T cell subsets derived from bulk RNA sequencing data of CXCR5⁻ CD4 T cell subsets in RA patients as depicted in Figure 3B. Subsets are defined by expression of PD-1, HLA-DR, and ICOS as noted. Paired t-test comparisons are shown. *p<0.05; **p<0.01; ns, non-significant.



Supplementary Figure 4. PD-1hi CXCR5- HLA-DR+ ICOS+ CD4 T cell frequencies are not significantly correlated with DLCO or FVC. Frequencies of PD-1hi CXCR5- HLA-DR+ ICOS+ CD4 T cell subset correlated with DLCO(%) shows r=.01, p=0.942 and correlation with FVC(%) shows r=-0.04, p=0.77.