TABLE E-1 Summary of Recent Literature on Blood Cobalt (Co) and Chromium (Cr) Levels Following Metal-on-Metal Hip Implants

Author	Implant*	Analytic Technique†	Blood Sample	Number of Implants	Time in Vivo *(yr)*	Chromium Reference Value‡	Mean Postop. Chromium Level	Increase in Cr *(postop./ref.)*	Cobalt Reference Value‡	Mean Postoperative Cobalt Level	Increase in Co *(postop./ref.)*
Skipor et al.[25]	Conserve Plus	AAS	Serum	25		0.08 µg/L (preop.)			0.17 µg/L (preop.)		
					0.25		1.88 µg/L	23.5		1.26 µg/L	7.4
					0.5		2.02 µg/L	25.3		1.20 µg/L	7.1
					1		1.8 µg/L	22.5		1.07 µg/L	6.3
Clarke et al.[7]						5 nmol/L (threshold)			5 nmol/L (threshold)		
	BHR	ICP-MS	Serum	16	Median, 1.3		50 nmol/L§	10		35.5 nmol/L§	7.1
	Cormet 2000 resurfacing	ICP-MS	Serum	6	Median, 1.3		80 nmol/L§	16		51 nmol/L§	10.2
	Ultima	ICP-MS	Serum	22	Median, 1.3		19 nmol/L§	3.8		22 nmol/L§	4.4
Back et al.[1]	BHR	ICP-MS (Co), AAS (Cr)	Serum	16		6 µmol/L (preop.)			5.69 µmol/L (preop.)		
					0.25		75.7 µmol/L	12.6		50 µmol/L	8.8
					0.5		85 µmol/L	14.2		56.56 µmol/L	9.9

					0.75		95 µmol/L	15.8		51.5 µmol/L	9.1
					1		76.9 µmol/L	12.8		40.2 µmol/L	7.1
					2		67.92 µmol/L	11.3		31.83 µmol/L	5.6
Iavicoli et al.[14]	Conserve Plus	ICP-MS	Serum	14	1.3	1.47 µg/L (19 controls)	2.88 µg/L	2	3.46 µg/L (19 controls)	14.0 µg/L	4.1
Savarino et al.[22]	Metasul	AAS	Serum	42	2.5 to 5.5	0.28 µg/L (47 controls)	2.10 µg/L	7.5	0.24 µg/L (47 controls)	1.57 µg/L	6.5
Witzleb et al.[29]		AAS	Serum		2	<0.25 µg/L§ (130 controls)			0.25 µg/L§ (130 controls)		
	BHR			111			5.12 µg/L§	20.5		4.28 µg/L§	17.1
	Metasul unilat.			60			1.22 µg/L§	5		1.7 µg/L§	6.8
	Metasul bilat.			14			2.5 µg/L§	10		3.18 µg/L§	12.7
Daniel et al.[8]	BHR	ICP-MS	Whole blood	26		0.3 µg/L (preop.)			0.2 µg/L (preop.)		
					1		2.4 µg/L	8		1.3 µg/L	6.5
					4		1.1 µg/L	3.7		1.2 µg/L	6
					6		1.1 µg/L	3.7		1.2 µg/L	6
Vendittoli et al.[26]	Durom	ICP-MS		53							

			Whole blood			0.92 µg/L			0.15 µg/L		
					0.25		2.01 µg/L	2.2		0.9 µg/L	6
					0.5		1.89 µg/L	2.1		0.8 µg/L	5.3
					1		1.61 µg/L	1.8		0.67 µg/L	4.5
					2		1.37 µg/L	1.5		0.59 µg/L	3.9
			Serum		1	1.26 µg/L (preop.)	2.2 µg/L	1.8	0.21 µg/L (preop.)	0.9 µg/L	4.3
Antoniou et al.[6]		ICP-MS	Whole blood			0.05 µg/L§ (40 controls)			1.75 µg/L§ (40 controls)		
	Metasul 28-mm head THA			28							
					0.5		0.35 µg/L§	7		2.5 µg/L§	1.4
					1		0.60 µg/L§	12		2.6 µg/L§	1.5
	Ultamet 36-mm head THA			58							
					0.5		0.25 µg/L§	5		1.8 µg/L§	1
					1		0.4 µg/L§	8		2.3 µg/L§	1.3

	ASR HRA			70							
					0.5		0.50 µg/L§	10		2.3 µg/L§	1.3
					1		0.50 µg/L§	10		2.4 µg/L§	1.4
Daniel et al.[9]		HR-ICP-MS	Whole blood			None			None		
	Metasul			20	1		1.7 µg/L	—		1.7 µg/L	—
	Large diameter THR			28	1		1.4 µg/L	—		2.3 µg/L	—
Moroni et al.[20]		GF-AAS	Serum								
	BHR			20	2	0.25 ng/mL (48 controls)	2.3 ng/mL	9.2	0.29 ng/mL (48 controls)	1.40 ng/mL	4.8
	Metasul			26	2.2	0.25 ng/mL (48 controls)	1.4 ng/mL	5.6	0.29 ng/mL (48 controls)	1.33 ng/mL	4.6
Savarino et al.[23]	Metasul	GF-AAS	Serum	16	10.1	0.26 ng/mL (47 controls)	0.86 ng/mL	3.3	0.27 ng/mL	0.69 ng/mL	2.6
Engh et al.[12]		HR-ICP-MS									

	28-mm THA: AML or Prodigy and Pinnacle shell			25							
			Erythrocyte			1.20 µg/L§ (preop.)			0.13 µg/L§ (preop.)		
					0.5		1.20 µg/L§	1		0.41 µg/L§	3.2
					1		1.10 µg/L§	0.9		0.42 µg/L§	3.2
					2		1.10 µg/L§	0.9		0.42 µg/L§	3.2
			Serum			0.22 µg/L§ (preop.)			0.16 µg/L§ (preop.)		
					0.5		0.99 µg/L§	4.5		0.72 µg/L§	4.5
					1		1.07 µg/L§	4.9		0.72 µg/L§	4.5
					2		1.29 µg/L§	5.9		0.77 µg/L§	4.8
	36-mm THA: AML or Prodigy and Pinnacle shell			32							
			Erythrocyte			0.90 µg/L§ (preop.)			0.11 µg/L§ (preop.)		

					0.5		1.10 µg/L§	1.2		0.32 µg/L§	2.9
					1		1.20 µg/L§	1.3		0.45 µg/L§	4.1
					2		1.20 µg/L§	1.3		0.42 µg/L§	3.8
			Serum			0.21 µg/L§ (preop.)			0.14 µg/L§ (preop.)		
					0.5		0.97 µg/L§	4.6		0.66 µg/L§	4.7
					1		1.06 µg/L§	5.1		0.70 µg/L§	5
					2		0.91 µg/L§	4.3		0.73 µg/L§	5.2
Lazennec et al.[16]		ET-AAS	Serum	84		0.30 µg/L§ (detection limit)			0.30 µg/L§ (detection limit)		
	Metasul THA unilateral										
					1		2.18 µg/L§	7.3		1.41 µg/L§	4.7
					3		2.05 µg/L§	6.8		1.69 µg/L§	5.6
					5		1.70 µg/L§	5.7		1.30 µg/L§	4.3
					7		1.42 µg/L§	4.7		1.69 µg/L§	5.6
					9		1.49 µg/L§	5.0		1.55 µg/L§	5.2

	Metasul THA bilateral			25		0.30 µg/L§ (detection limit)			0.30 µg/L§ (detection limit)		
					1		2.60 µg/L§	8.7		1.69 µg/L§	5.6
					3		2.61 µg/L§	8.7		2.33 µg/L§	7.8
					5		2.83 µg/L§	9.4		2.82 µg/L§	9.4
					7		2.41 µg/L§	8		1.89 µg/L§	6.3
					9		2.99 µg/L§	10		2.03 µg/L§	6.8
deSouza et al.[10]	Corin HRA	ETA-AAS up to 3 years, HR-ICP-MS after 3 years	Serum	56		11.3 nmol/L (preop.)			10.0 nmol/L		
					0.5		70.8 nmol/L	6.3		52.3 nmol/L	5.2
					1		104.1 nmol/L	9.2		80.4 nmol/L	8
					1.5		112.9 nmol/L	10		78.3 nmol/L	7.8
					2		117.2 nmol/L	10.4		95.5 nmol/L	9.6
					3		111.8 nmol/L	9.9		86.9 nmol/L	8.7
					4		96.5 nmol/L	8.5		74.5 nmol/L	7.5
					5		76.7 nmol/L	6.8		64.9 nmol/L	6.5

					6		95.0 nmol/L	8.4		68.9 nmol/L	6.9
					7		114.6 nmol/L	10.1		87.4 nmol/L	8.7
					8		102.4 nmol/L	9.1		102.9 nmol/L	10.3
					9		99.3 nmol/L	8.8		81.8 nmol/L	8.2
					10		116.4 nmol/L	10.3		86.5 nmol/L	8.7
Garbuz et al.[13]		HR-SF-ICP-MS	Serum			0.15 µg/L§ (preop.)			0.13 µg/L§ (preop.)		
	Durom resurfacing			48							
					1		0.81 µg/L§	5.4		0.51 µg/L§	3.9
					2		0.84 µg/L§	5.6		0.54 µg/L§	4.2
	Metasul large head and Durom cup			56		0.20 µg/L§ (preop.)			0.11 µg/L§ (preop.)		
					1		2.14 µg/L§	10.7		5.09 µg/L§	46.3
					2		2.88 µg/L§	14.4		5.38 µg/L§	48.9
Imanishi et al.[15]	THA with 36-mm Pinnacle-A	ICP-MS (Co), GF-AAS (Cr)	Serum	33		0.3 µg/L§ (preop.)			0.3 µg/L§ (preop.)		

					0.25		0.6 µg/L§	2		0.7 µg/L§	2.3
					1		0.8 µg/L§	2.7		1.1 µg/L§	3.7
Vendittoli et al.[27]		ICP-MS	Whole blood								
	Metasul THR			53		1.03 µg/L (preop.)			0.15 µg/L (preop.)		
					0.25		1.53 µg/L	1.5		0.71 µg/L	4.7
					0.5		1.65 µg/L	1.6		0.87 µg/L	5.8
					1		1.50 µg/L	1.5		0.81 µg/L	5.4
					2		1.62 µg/L	1.6		0.94 µg/L	6.2
	Durom (48.8-mm bearing)			64		0.88 µg/L (preop.)			0.16 µg/L (preop.)		
					0.25		2.00 µg/L	2.3		0.89 µg/L	5.6
					0.5		1.84 µg/L	2.1		0.78 µg/L	4.9
					1		1.56 µg/L	1.8		0.67 µg/L	4.2
					2		1.58 µg/L	1.8		0.67 µg/L	4.2
Vendittoli et al.[28]	LDH-THA (47.6 mm)	HR-SF-ICP-MS	Whole blood	29		0.78 µg/L (preop.)			0.11 µg/L (preop.)		

					0.5		1.27 µg/L	1.6		1.96 µg/L	17.8
					1		1.34 µg/L	1.7		2.21 µg/L	20.1
Pattyn et al.[21]		ICP-MS	Whole blood								
	Metasul			10		0.48 µg/L (limit)			0.48 µg/L (limit)		
					1		1.79 µg/L	3.7		2.02 µg/L	4.2
					2		1.25 µg/L	2.6		1.79 µg/L	3.7
	Durom			22		0.48 µg/L (limit)			0.48 µg/L (limit)		
					1		1.03 µg/L	2.1		1.07 µg/L	2.2
					2		1.07 µg/L	2.2		0.79 µg/L	1.7
	BHR			20		0.48 µg/L (limit)			0.48 µg/L (limit)		
					1		1.50 µg/L	3.1		2.07 µg/L	4.3
					2		1.54 µg/L	3.2		1.86 µg/L	3.9
Yang et al.[30]	Conserve Plus	ETA-AAS	Serum	25		6.91 nmol/L (preop.)			6.63 nmol/L (preop.)		
					0.25		34.37 nmol/L	5		24.62 nmol/L	3.7
					0.5		69.80 nmol/L	10.1		51.47 nmol/L	7.8

					0.75		54.06 nmol/L	7.8		31.65 nmol/L	4.8
					1		41.52 nmol/L	6		27.14 nmol/L	4.1
					2		35.22 nmol/L	5.1		23.92 nmol/L	3.6

*Conserve Plus system (Wright Medical Technology, Arlington, Tennessee); Durom resurfacing system (Zimmer, Winterthur, Switzerland; Zimmer Inc., Warsaw, Indiana); Metasul (Sulzer AG Orthopedics Ltd., Winterthur, Switzerland); Metasul 28-mm head (Zimmer, Warsaw, Indiana); Metasul large head (Zimmer, Warsaw, Indiana); BHR = Birmingham Hip Resurfacing Device (Midland Medical Technologies, Birmingham, United Kingdom); Cormet 2000 Resurfacing (Corin Surgical, Cirencester, United Kingdom); Ultima (Johnson & Johnson, Leeds, United Kingdom); Ultamet (DePuy Orthopaedics); ASR=Articular Surface Replacement (DePuy Orthopaedics); large diameter THR (42-54 mm; Smith & Nephew Orthopaedics, Warwick, United Kingdom); Corin (Cirencester, United Kingdom); AML or Prodigy and Pinnacle (DePuy Orthopaedics, Warsaw, Indiana); LDH = large diameter head; THA = total hip arthroplasty; THR = total hip replacement; HRA = hip resurfacing arthroplasty. †AAS = atomic absorption spectrophotometry; GF-AAS = graphite furnace atomic absorption spectrophotometry; ET = electrothermal; ETA = electrothermal atomization; ICP-MS = inductively coupled plasma mass spectrometry; HR-ICP-MS = high resolution inductively coupled plasma mass spectrometry; HR-SF-ICP-MS = high resolution sector field inductively coupled plasma mass spectrometry. ‡Mean preoperative level or reference value or concentration in control group. §Median value.