TABLE E-1 Wear Rate Data Obtained from the Literature for Both Retrieval Analysis and Simulator Studies*

				Wear Results		
Study	Prosthesis Type	Initial Diameter *(mm)*	Diametral Clearance *(μm)*	Wear Rate or Wear Volume	Bedding-In Wear Volume	Steady-State Wear Rate
Retrieval Analysis						
Wear measured on head only						
McKellop et al.[1]	McKee-Farrar	34.9 to 41.3	135 to 1748	0.6 to 11.2 mm^3/yr for 1 to 10 yr		
McKellop et al.[1]	Müller	37 to 42	210 to 500	0.9 to 3.9 mm^3/yr; mean 2.46 mm^3 for 8 to 13 yr		
Wear measured on head and cup						
Kothari et al.[21]	McKee-Farrar	40	200 typ	0.5 to 8.5 mm^3/yr		
McKellop et al.[1]	McKee-Farrar	34.9	127 to 386	0.12 to 0.89 mm^3/yr		
Head				Mean 0.414 mm^3/yr for 20 to 25 yr		
Cup				Mean 0.345 mm^3/yr for 20 to 25 yr		
Rieker et al.[22]	Metasul	28	NA	Mean 25 μm/yr for up to 12 mo		
Rieker et al.[22]	Metasul	28	NA	Mean 5 μm/yr for 2 to 9 yr		
Weber et al.[23]	Weber	28	NA	5 to 15 μm/yr for 8 to 12 mo		
Weber et al.[23]	Weber	28	NA	3 to 7 μm/yr for 2 to 6 yr		
Weber et al.[23] and Semlitsch et al.[25]	Müller	42	210 to 500	2 to 6 μm/year for 10 to 20 yr		
Simulator studies						
Farrar and Schmidt[27]	CoCrMo	28	NA		0.69 mm^3 for 2 million cycles	
Vassiliou et al.[15]	BHR	50	160 to 210		1.84 mm^3 up to 1×10^6 cycles; 0.64 mm^3 up to 3×10^6 cycles	0.24 mm^3 up to 5×10^6
Hu et al.[28]	Adept	50	190		2.41 mm^3 up to 1.2×10^6 cycles; 0.54 mm^3 up to 3.1×10^6 cycles	0.08 mm^3 up to 5.5×10^6
Bowsher et al.[6]	McMinn (Corin)	40	220		2.3 mm^3	0.48 mm^3
Schmidt et al.[13]	Metasul	28 to 32	NA		20 μm for one million cycles	2 to 4 μm for 2.5×10^6

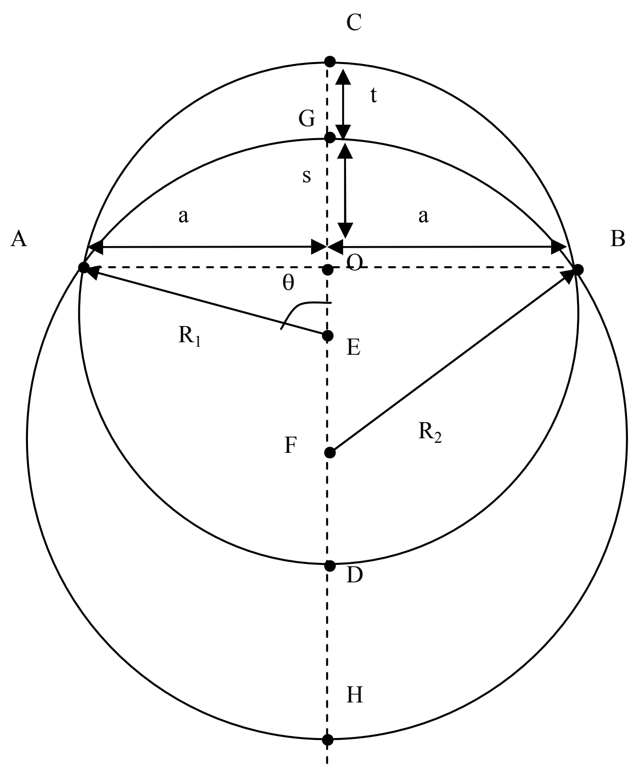
Chan et al.[7]	Heat-treated high-carbon cast alloy	45	10, 300		0.2 to 8 mm^3 at 0.5 × 10^6cycles	0.6 mm^3 up to 3 × 10^6
Chan et al.[7]	Wrought low carbon	45	89 to 178		0.2 to 0.7 mm^3 at 0.2 × 10^6 cycles	0.15 to 0.17 mm^3 up to 3 × 10^6
Chan et al.[8]	Cast high carbon	28	10 to 86		0.21 mm^3 at 1 × 10^6 cycles	0.063 mm^3 up to 3 × 10^6
Chan et al.[8]	Wrought high carbon	28	35 to 76		0.24 mm^3 at 1 × 10^6 cycles	0.067 mm^3 up to 3 × 10^6
Chan et al.[8]	Low carbon	28	86 to 101		0.76 mm^3 at 1 × 10^6 cycles	0.11 mm^3 up to 3 × 10^6
Bowsher et al.[6]	As cast	40	220		2.4 mm^3 at 1 × 10^6 cycles	0.48 mm^3 up to 3 × 10^6
Anissian et al.[5]	Metasul	28	96.55		2.23 mm^3 at 1 × 10^6 cycles	0.69 mm^3 up to 4 × 10^6
Dowson et al.[10]	As cast	54	254 to 307		3.28 mm^3 at 2 million cycles	0.17 mm^3 up to 5 × 10^6
Dowson et al.[10]	As cast head heat-treated cup	54.5	83 to 129		0.79 mm^3 at 2 million cycles	0.09 mm^3 up to 5 × 10^6
Williams et al.[16]	Ultima	28	60		2.03 mm^3	0.22 mm^3 up to 5 × 10^6
Goldsmith et al.[12]	Wrought	36	71		1 to 3 mm^3 at 1 to 2 million cycles	0.36 mm^3 up to 5 × 10^6
Goldsmith et al. [12]	Wrought	36	71		Very small	0.07 mm^3 up to 3.4 × 10^6
Firkins et al.[11]	Wrought high carbon	28	60		0.33 mm^3 at 1 million cycles	0.023 mm^3 up to 2 × 10^6
Clarke et al.[9]	Metasul	28	111		2.684 $mm^3/10^6$ cycles for 0.3 to 0.6 × 10^6 cycles	0.977 mm^3 up to 4.2 × 10^6
Scholes et al.[14]	Low-carbon cup	28	NA		0.58 mm^3 for 2 million cycles	

*typ = various types of hip simulators; CoCrMo = cobalt-chromium-molybdenum; NA = not available; BHR = Birmingham Hip Resurfacing.

Appendix

Mathematical Model

The head is worn from a sphere of radius R_1, center E, to a sphere or radius R_2, center F, with a wear depth t



Using chords in circle properties, OC.OD=OA.OB gives:

$$s = R_1 - \frac{\sqrt{4R_1^2 - a^2}}{2} - t$$

With $R_1 \sin\theta = \frac{a}{2}$:

$$s = R_1(1 - \cos\theta) - t$$

With OG.OH=OA.OB

$$s(2R_2 - s) = \left(\frac{1}{2}a\right)^2$$

Hence

$$R_2 = \frac{(R_1(1-\cos\theta) - t)^2 + R_1^2 \sin^2\theta}{2(R_1(1-\cos\theta) - t)}$$

These calculations can be repeated for a cup of radius R_3 wearing to a radius R_4, with a wear depth t′.

$$R_4 = \frac{(R_3(1-\cos\theta) - t')^2 + R_3^2 \sin^2\theta}{2(R_3(1-\cos\theta) - t')}$$

The original clearance is c = R_3-R_1. The effective clearance during the wear mechanism is c_{eff} = R_4-R_2.

$$c_{eff} = \frac{(R_1(1-\cos\theta) - t)^2 + R_1^2 \sin^2\theta}{2(R_1(1-\cos\theta) - t)} - \frac{(R_3(1-\cos\theta) - t')^2 + R_3^2 \sin^2\theta}{2(R_3(1-\cos\theta) - t')}$$

Because the linear wear is very small compared with the component radius, all $\frac{t^2}{R}$ terms tend toward zero and are assumed to be negligible. C_{eff} can therefore be simplified to:

$$c_{eff} = c - \frac{\cos\theta}{1-\cos\theta}(t + t')$$

If c_{eff} = 0 and the total linear wear is T=t+t′:

$$c = \frac{\cos\theta}{1-\cos\theta}T$$

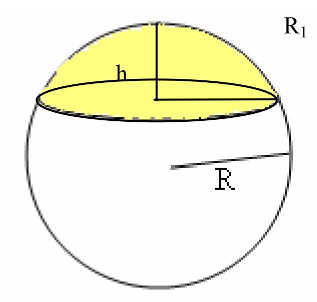
Or

$$(1)\,T = \frac{C(1-\cos\theta)}{\cos\theta}$$

The wear volume on the head can be calculated by subtracting the spherical cap volume of the original geometry from the spherical cap volume for the worn geometry.

The volume of a spherical cap is given by:

$$V = \pi\frac{\pi}{6}(3r_1^2 + h\quad)h$$



In the worn head and cup case:

$$V = \frac{\pi}{6}\left(3\left(R_1 \sin\theta\right)^2 + \left(T+s\right)^2\right)\left(T+s\right) - \frac{\pi}{6}\left(3\left(R_1 \sin\theta\right)^2 + s^2\right)s$$

Assuming t^3 is negligible, this can be simplified to

$$V = \frac{\pi R_1 T\left(1-\cos\theta\right)}{2}\left(2R_1 - T\right)$$

With $T = \frac{1-\cos\theta}{\cos\theta}c$,

(2) $$V = \frac{\pi}{2}\left[R_1 \frac{C\left(1-\cos\theta\right)^2}{\cos\theta}\left(2R_1 - \frac{C\left(1-\cos\theta\right)}{\cos\theta}\right)\right]$$

Since radial clearance C is typically 2 orders of magnitude less than the head radius R_1 the equation can be simplified to:-

$$V = \pi R_1^2 c\frac{\left(1-\cos\theta\right)^2}{\cos\theta}$$

Or

(3) $$V = \frac{\pi}{2}R_1 T\left(1-\cos\theta\right)\left(2R_1 - T\right)$$