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Simultaneous Achievement of Sterility Assurance Level (SAL) of 10^{-6} and Material and Functional Compatibility in Gas Plasma Sterilization

Running Title: Simultaneous SAL and Compatibility

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Abstract

In the existing sterilization procedures, it is quite hard or impossible to achieve sterility assurance level (SAL) of 10^{-6} and material/functional compatibility simultaneously. Simultaneous achievement of both is required in ISO 14161 and sterilization validation. As gas plasma sterilization penetration was quite shallow at around 10-20 nm level from the surface, so it can kill only one layer of bioburden and can maintain material and functional compatibility in success without any difficulties. Bioburden means sort and number of viable microorganisms in/or the products. It is so-called contaminant. Sterilization was finished in success but material was damaged and useless, such a phenomenon must be avoided. In the current sterilizations, gamma-ray irradiation, electron-beam irradiation, autoclaving, dry heating, hydrogen peroxide gas or ethylene oxide gas sterilization has inferiority not to obtain material and functional compatibility. If gas plasma sterilization will be applicable to the real healthcare products, simultaneous achievement of SAL of 10^{-6} and material/functional compatibility can attain without any difficulties, at that time simultaneous achievement is addressed to the existing sterilization procedures and sterilization validation. In that means gas plasma sterilization is the future promise sterilization procedure because only gas plasma sterilization can achieve both in success.

Keywords: Plasma; Sterilization; Microorganisms; Irradiation

Introduction

Gas plasma sterilization is popular among sterilization researchers and small number of commercial base gas plasma equipment is available from for example AST Products Inc (http://www.astp.com/plasma-equipment). Sterad^{R} from J & J is not exact H_2O_2 gas plasma. Plasma is used for aeration of residual H_2O_2. However, gas plasma sterilization is not popular due to narrower space of sterilization chamber. Sterilization is the toughest concept against microorganisms. Sterilization can kill all types of microorganisms including spores and vegetative cells [1-3]. Spores are the most tolerable organisms among microorganisms (Table 1). In addition according to ISO 14161 and sterilization validation, exact sterilization must attain sterility assurance level (SAL) of 10^{-6} and initial population of 10^{6} CFU (Colony Forming Unit). From initial population down to SAL 10^{-6} is required 12 log reduction. It's a mistake that from initial population of 10^{6} CFU/carrier to 10^{0} CFU/carrier, which is not correct requirement of 6 log reduction. The correct 6 log reduction is from 10^{0} CFU/carrier to SAL of 10^{-6} in ISO 14161 and sterilization validation. For that purpose straight survivor curve must be indispensable. Initial population of 10^{0} CFU/carrier is the resemble population to bioburden and SAL of 10^{-6} is definitely required in ISO 11138-1 and ISO 14161 as well as sterilization validation by the authority. The six log reduction required to BI user is the absolute bioburden method in ISO 14161. This requ1irement is not addressed to BI manufacturer in ISO 11138-1.

Requirement of Sterilization Procedure

This requirement exists in sterilization validation and ISO 14161 and 11138-1. To attain SAL of 10^{-6}, survivor curve must be straight from the initial population (No) to half-cycle window (SAL 5 to SAL 10^{-1}) must be straight (Figure 1) and from SAL 10^{-1} to SAL 10^{-2} can be confirmed experimentally straight and from SAL of 10^{-2} to SAL of 10^{-6} speculated to be straight because from SAL of 10^{-3} to SAL of 10^{-6} cannot be confirmed experimentally and only speculated from stochatics in ISO 11137-1. Up to SAL of 10^{-2} (1/100) it can be confirmed experimentally, but less than SAL 10^{-3} (1/1000), it has more possibility to be contaminated, thus exact SAL is uncertain below SAL of 10^{-3}. Therefore, SAL of 10^{-6} is the speculation and this amount is defined as the closest amount to zero from stochastics and this concept is explained in ISO 11137-1. In this means that during 6 log reduction, any tailing

	Microorganism	Examples
More resistant	Prions	Scrapie, Creutzfedt-Jakob disease chronic wasting disease
	Bacterial spores	*Bacillus, Geobacillus, Clostridium*
	Protozoal oocysts	*Cryptosporidium*
	Helminth egg	*Ascaris, Enterobius*
	Mycobacteria	*Micobacterium tuberculosis, M terrae, M chelonea*
	Small, Nonenveloped virus	*Poliovirus, Parvoviruses, papillomaviruses*
	Protozoal cysts	*Giardia, Acanthamoeba*
	Fungal spores	*Aspergillus ,penicillium*
	Gram–negative bacteria	*Pseudomonas, Providencia, Escherichia*
	Vegetative fungi and algae	*Aspergillus, Trichophyton, Candida. Chlamydomonas*
Less resistant	Vegetative Helminth and Protozoa	*Ascaris, Cryptosporidium, Giardia*
	Lagre, Nonenveloped virus	*Adenovirus, Rotavirus*
	Gram–positive bacteria	*Staphylococcus, Streptococcus, Enterococcus*
	Enveloped virus	Human immunodeficiency virus, hepatitis B virus, Herpex simplex virus

Table 1: Tolerance order to sterilants among microorganisms.

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curve due to clumping (Figure 4) (Curved survivor line, Figure 5A) is not approved. The reason why tailing curve can be observed and how to avoid this is also explained in the NOVA book [1-3], but curved survivor line less than 6 log can be observed in the papers and books from engineering researchers. All of them are invalid data.

Initial population of 10^6 CFU/carrier down to SAL of 10^{-6} is quite difficult to attain by gas plasma sterilization because the penetration depth of gas plasma is quite shallow at around 10 to 20 nm [4] (Figure 2). Figure 2 was the polystylene surface after (upper) and before (lower) gas plasma exposure and observed by Atomic Force Microscopy (AFM). From the upper figure, it can observe to be etched around the depth of 10 to 20 nm. From the presented scale the deepest etched depth can speculate to be around 20 nm. From this, the average etching scale is around 10-20 nm. The *Geobacillus stearothermophilus* ATCC 7953 spore has 1 m width and 3 μm length (Figure 3), indicating gas plasma cannot pass through even one spore. This indicates gas plasma can kill only one layer of spore and multi layers cannot kill sufficiently from the shallow penetration depth. Multi-layers (clumping, Figure 4) are the reason why survival curve presents curved line before SAL of 10^0 [1-3]. Multi-layers are called clumping among microbiologists (Figure 4) and same phenomenon as stacking among engineering researchers, must be avoided to obtain straight survival curve up to SAL of 10^{-6}, not SAL of 10^0 (Figure 5).

As gas plasma sterilization was quite shallow penetration depth, so products themselves are quite safe from damage, indicating simultaneous achievement of SAL of 10^{-6} and material/functional compatibility can easily obtain compared with the existing sterilization procedures such as gamma-ray irradiation, autoclaving, dry heating, hydrogen peroxide gas sterilization, ethylene oxide gas sterilization and so on [5-78].

We have a data to indicate gas plasma sterilization does not cause serious damage to the material. Polystylene (PS) was sterilized by

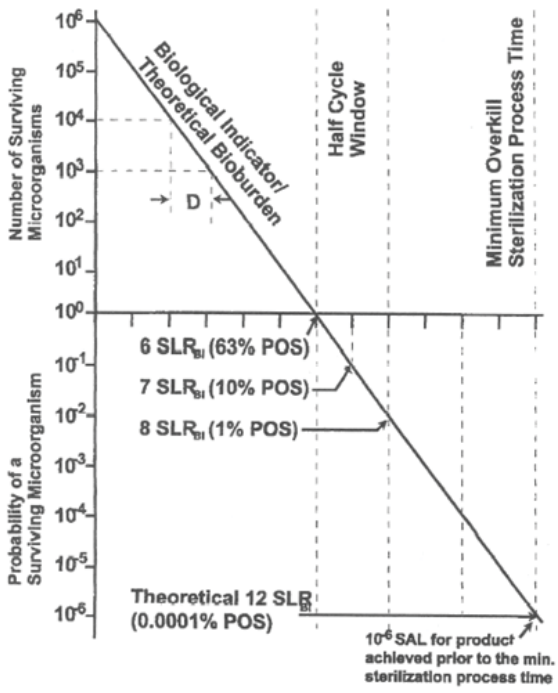

Figure 1: Necessity to attain SAL of 10^{-6} and straight survivor curve from initial population to SAL 10^{-6}

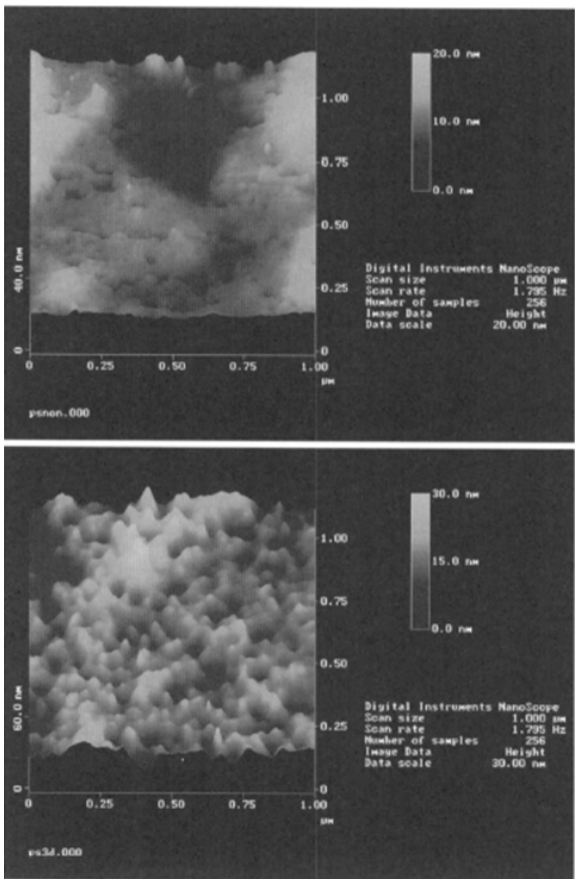

Figure 2: Surface analysis of atomic force microscopy (AFM) before and after gas plasma exposure to polystylene (PS) Upper is after treatment for 7 min and lower is before treatment (control)

Figure 3: Scanning electron microscopy (SEM) of *Geobacillus stearothermophilus* ATCC 7953, which spore is defined as biological indicator (BI) of gas plasma sterilization

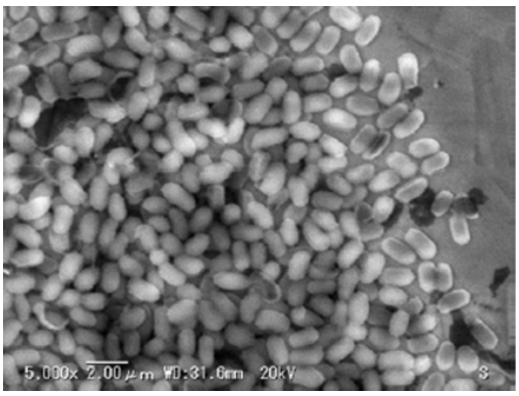

Figure 4: State of clumping of *Geobacillus stearotheermophilus* ATCC 7953

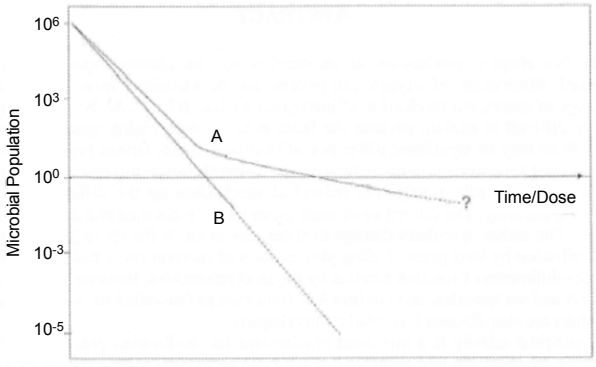

Figure 5: Straight line and tailing line of survivor curves

nitrogen gas plasma and determined the amount of CO, NOx, HCN, O_3 and N_2O before and after gas plasma exposure. These amounts were individually determined and all are less than safety level, indicating no significant deterioration of PS can be observed (Table 2). FT-IR data before and after gas plasma exposure to PS indicated that no significant change (for example no oxidation at 1670 cm^{-1} which is C=O functional group) after treatment for 7 min (Figure 6). In addition we have a data of nitrogen gas plasma exposure and autoclaving to scalpel (Figures 7 and 8). The result indicated that scalpel was unchanged before and after nitrogen gas plasma treatment for 8 min and 40 min (Figure 7), but significantly damage can be observed after autoclaving for 15 min at 121.1°C (Figure 8). From these, nitrogen gas plasma sterilization can be easily attained simultaneous achievement of SAL of 10^{-6} and material and functional compatibility in success [4,17,79].

In addition, we have a tensile and elongation strength test of Latex rubber before and after nitrogen gas plasma exposure (Table 3) [4,80-88] and leaching test of latex rubber before and after nitrogen gas plasma exposure (Table 4) [4,89-91]. Using Table 3 data, it is statistically tested with Student *t* test (paired *t* test using Statt View^R) and no significant difference was observed. In Table 4, statistical analysis cannot be done, but it can speculate that the significant difference may not exist.

Conclusion

As mentioned in the above, gas plasma sterilization can attain SAL of 10^{-6} and material/functional compatibility without any difficulties because penetration depth of the sterilization factors can be only 10-20 nm from the surface, which can kill only scattering bioburden in one layer on the products. Both achievement of SAL of 10^{-6} and material/functional compatibility can be completed in success required in ISO 14161 and sterilization validation to the BI user by the authority. The existing sterilization procedures are all failed to attain material and functional compatibility in the exact status, therefore compatibility is not strictly applied to the existing sterilization procedures, and if strictly applied to the existing sterilization procedures, no sterilization procedures are available in the current status, so the use of the existing procedures was connived. But this kind of status is not correct and the real procedures to attain SAL of 10^{-6} and material/functional compatibility must be realized.

Procedure	Before and After Treatment to PS	Detected Gases, ppm				
Low Pressure Gas plasma	Sort of gases	CO[1]	NOx[2]	HCN[3]	O_3[4]	N_2O[5]
	Before	<2	<0.5	N.D.	N.D.	N.D.
	After	3.9	1.1	<0.1	<0.05	2.6

The data is cited from Shintani et al, Biocontrol Science (2007), 12, 131-143.
1 UV-absorbance method
2 chemical luminescence method
3 pyrazolone light absorption method
4 ozone detector
5 GC-MS
N.D. not detected, indicating less than limit of detection (LOD)

Table 2: Analysis of exhaust gas from polystylene (PS) treated with nitrogen gas plasma

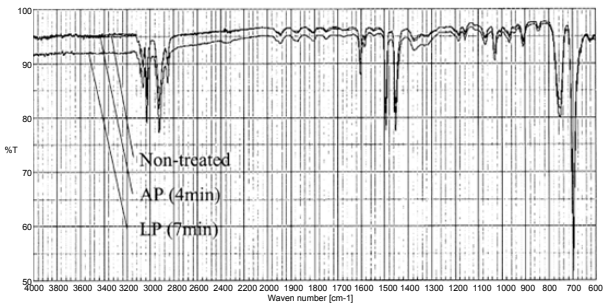

Figure 6: FT-IR data of PS before and after gas plasma exposure for 7 min treatment AP: atmospheric pressure and LP: Low pressure

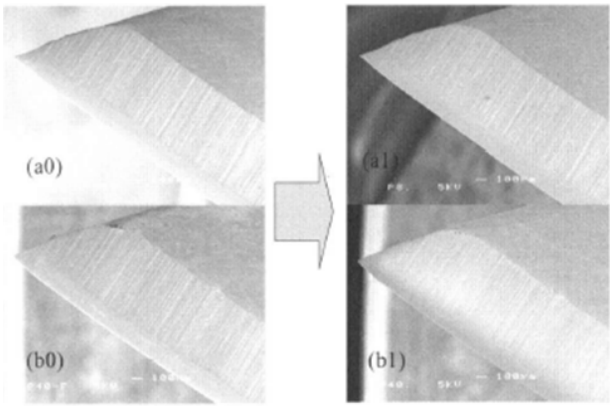

Figure 7: SEM observation of a scalpel before and after gas plasma exposure (a0) is control and (a1) is 8 min treatment. (b1) is control and (b1) is 40 min exposure.

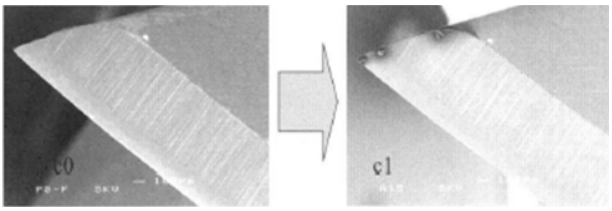

Figure 8: SEM observation of a sclpel before and after autoclave treatment for 15 min at 121.1 °C C1 is after treatment and c0 is control.

Sample	No	Max Tensile test (N)	Max elongation test (%)	300% Elongation tensile test (N)
Non treatment	1	3.58	656.0	1.32
	2	3.83	684.5	1.09
	3	3.73	781.5	1.35
	4	3.73	695.0	1.33
	5	3.70	678.0	1.30
	Ave	3.71	699.0	1.28
Plsama 40 min	1	3.30	685.5	1.24
treatment	2	3.45	694.5	1.25
	3	3.98	788.0	1.15
	4	3.80	626.5	1.43
	5	4.73	812.5	1.32
	Ave	3.85	721.4	1.08

Table 3: Tensile test, elongation test and 300% elongation test of Latex rubber before and after nitrogen gas plasma exposure

Sample	Heavy metal	Arsenic (As)	UV absorbance	Potassium permanganate	Evaporation residue
Non treatment	Less than 2.0 ppm	Less than 2.0 ppm	[220 nm[0.3447 [350 nm] 0.0562	8.90 µg/mL	2.0 mg
Plasma 40 min exposure	Less than 2.0 ppm	Less than 2.0 ppm	[220 nm[0.3498 [350 nm] 0.0479	9.22 µg/mL	3.7 mg

Table 4: Leaching test of Latex rubber before and after of nitrogen gas plasma exposure

If gas plasma sterilization procedures can be applicable to the real healthcare materials, the present connivance to the existing sterilization procedures cannot be approved by the authority in future. It may be required to improve in order to attain SAL of 10^{-6} and material and functional compatibility to the existing sterilization procedures. In that meaning commercial base gas plasma sterilizer is anticipated as soon as possible. Sterad[R] from J & J is not real H_2O_2 plasma sterilizer, but simply H_2O_2 sterilizer because chamber is too large when considering as H_2O_2 plasma sterilizer because sterilization factors are short-lived and small flight distance. Plasma in Sterad[R] is used for H_2O_2 residue removal, not for sterilization.

References

1. Sakudo A, Shintani H (2011) Sterilization and disinfection by plasma : sterilization mechanisms, biological, and medical applications. In: Shintani H, McDonnell G (eds) Definition of sterilization, disinfection, decontamination, and antisepsis. Nova Science Publishers, New York, USA.
2. Sakudo A, Shintani H (2011) Sterilization and disinfection by plasma : sterilization mechanisms, biological, and medical applications. In: Shintani H, McDonnell G (eds) Inactivation of microorganisms (spore and vegetative cells) and the mechanisms by gas plasma. Nova Science Publishers, New York, USA.
3. Sakudo A, Shintani H (2011) Sterilization and disinfection by plasma : sterilization mechanisms, biological, and medical applications. In: Shintani H, McDonnell G (eds) Several points to consider when conducting plasma experiments. Nova Science Publishers, New York, USA.
4. Shintani H, Shimizu N, Imanishi Y, Sekiya T, Tamazawa K, et al. (2007) Inactivation of microorganisms and endotoxins by low temperature nitrogen gas plasma exposure. Biocontrol Science 12: 131-143.
5. Shintani H (1995) The relative safety of gamma-ray, autoclave, and ethylene oxide gas sterilization of thermosetting polyurethane. Biomed Instrument Technol 29: 513-519.
6. Bathina MN, Mikelsen S, Brooks C, Jaramillo J, Hepton T, et al. (1998) Safety and efficacy of hydrogen peroxide plasma sterilization for repeated use of electrophysiology catheters. J Am Coll Cardiol 32: 1384-1388.
7. Feldman LA, Hui HK (1997) Compatibility of medical devices and materials with low-temperature hydrogen peroxide gas plasma. Medical Device and Diagnostic Industry 19: 57-63.
8. Wood L, Getty J Plasma processing for optimal medical device manufacturing.
9. Penna, TC, Ferraz CA, Cassola MA (1999) The presterilization microbial load on used medical devices and the effectiveness of hydrogen peroxide gas plasma against Bacillus subtilis spores. Infect Control Hosp Epidemiol 20, 465-472.
10. Du Pont. Tyvek[R] offers unmatched sterilization compatibility.
11. Rao TV (2011) Gas Plasma Sterilization.
12. Kunishima H et al. (2005) A comparative study of ethylene oxide, hydrogen peroxide gas plasma and low temperature steam formaldehyde sterilization. Inf Control Hosp Eoidemiol 26: 486-489.
13. Willie BM, Ashrafi S, Alajbegovic S, Burnett T, Bioebaum RD (2004) Quantifying the effect of resin type and sterilization method on the degradation of ultrahigh molecular weight polyethylene after 4 years of real-time shelf aging. J Biomed Mater Res 69: 477-489.
14. Brown SA, Merritt K, Woods TO, McNamee SG, Hitchins VM (2002) Effects of different disinfection and sterilization methods on tensile strength of materials used for single-use devices. Biomed Instrument Technol 36: 23-27.
15. Fisher J, Reeves EA, Isaac GH, Saum KA, Sanford WM (1997) Comparison of the wear of aged and non-aged ultrahigh molecular weight polyethylene sterilized by gamma irradiation and by gas plasma. J Mater Sci Mater Merd 8: 375-378.
16. Volny M, Elam WT, Ratner B.D, Turecek K (2007) Enhanced *in-vitro* blood compatibility of 316L stanless steel surfaces by reactive landing of hyaluronions. J Biomed Mater Res 80: 505-510.
17. Kwok SC, Yang P, Wang, J, Liu X, Chu PK (2004) Hemocompatibility of nitrogen-doped, hydrogen-free diamond-like carbon prepared by nitrogen gas plasma immersion ion implantation-deposition. J Biomed Mater Res 70: 107-114.
18. Williams RL, Wilson DJ, Rhodes NP (2004) Stability of plasma-treated silicone rubber and its influence on the interfacial aspects of blood compatibility. Biomaterials 25: 4659-4673.
19. Olde MR (2001) Structural and chemical modification of polymer surfaces by gas plasma etching. In: Engbers GH, Grijpma DW, Feijen J (eds) Gas plasma etching of PEO/PBT segmented block copolymer films Printpartners Ipskamp, Enschede, Netherlands. 121-142.
20. Lin JC, Cooper SL (1995) Surface characterization and *ex vivo* blood compatibility study of plasma-modified small diameter tubing; effect of sulphur dioxide and hexamethyldisiloxane plasmas. Biomaterial 16: 1017-1023.
21. Courtney JM, Park GB, Prentice CR, Winchester JF, Forbes CD (1978). Polymer modification and blood compatibility. J Bioeng 2: 241-249.
22. Hauser J, Esenwein SA, Awakowicz P, Steinau HU, Koeller M, et al. (2011) Sterilization of heat-sensitive silicone implant material by low-pressure gas plasma. Biomed Instrument Technol 45: 75-79.
23. Deilmann M, Halfmann H, Bibinov N, Wunderlich J, Awakowicz P (2008) Low-pressure microwave plasma sterilization of polyethylene terephthalate bottles. J Food Prot 71: 2119-2123.
24. Hauser J, Halfmann H, Awakowicz P, Koeller M, Essenwein SA (2008) A double inductively coupled low-pressure plasma for sterilization of medical implant materials. Biomed Tech 63: 199-203.
25. Simmons A, Hyvarinen J, Poole-Warren L (2006) The effect of sterilization on

a poly(dimethylsiloxine)/poly(hexamethylene oxide) mixed macrodiol-based polyurethane elastmer. Biomaterials 27: 4484-4497.

26. Hopper RH, Young AM, Orishimo KF, Engh CA (2003) Effect of terminal sterilization with gas plasma or gamma radiation on wear of polyethylene liners. J Bone Joint Surg Am 85: 464-468.

27. Charlebois SJ, Daniels AU, Lewis G (2003) Isothermal microcalorimetry an analytical technique for assessing the dynamic chemical stability of UHMWPE. Biomaterials 24: 291-296.

28. Trostle SS, Hendrickson DA, Franke C (2002) The effects of ethylene oxide and gas plasma sterilization on failure strength and failure mode of pre-tied monofilament ligature loops. Vet Surg 31: 281-284.

29. McNulty DE, Liao YS, Haas BD (2002) The influence of sterilization method on wear performance of the low contact stress total knee system. Orthopedics 25: s243-6.

30. Ferreira SD, Dernell WS, Powers BE, Schochet RA, Kuntz CA, et al. (2001) Effect of gas-plasma sterilization on the osteoinductive capacity of demineralized bone matrix. Clin Orthop Reiat Res 388: 233-239.

31. Liao WT, Lee WJ, Chen CY, Shih M (2001) Decomposition of ethylene oxide in the RF plasma environment. Environment Technol 22: 165-173.

32. Duffy RE, Brown SE, Caldwell KL, Lubniewski A, Anderson N, et al. (2000) An epidemic of corneal destruction caused by plasma gas sterilization. The Toxic Cell Destruction Syndrome Investigative Team. Arch Opthalnol 118: 1167-1176.

33. Reeves EA, Barton DC, FitzPatrick DP, Fisher J (2000) Comparison of gas plasma and gamma irradiation in air sterilization on the delamination wear of the ultra-high molecular weight polyethylene used in knee replacements. Proc Inst Mech Eng H 214: 249-255.

34. Lewis G, Nyman JS (1999) A new method of determining the J-inteegral fracture toughness of very tough polymers; application to ultra high molecular weight polyethylene. J Long Term Eff Med Implants 9: 289-301.

35. Hury S, Vidal DR, Desor F, Pelletier J, Lagarde T (1998) A parametric study pf the destruction efficiency of Bacillus spores in low pressure oxygen-based plasmas. Lett Appl Microbiol 26: 417-421.

36. Collier JP, Sutula LC, Currier BH, Currier JH, Wooding RE, et al. (1996) Overview of polyethylene as a bearing material; comparison of sterilization methods. Clin Orthop Relat Res 333: 76-86.

37. Hesby RM, Haganman CR, Stanford CM (1997) Effects of radiofrequency glow discharge on impression material surface wettability. J Prosthet Dent 77: 414-422.

38. Baier RE, Carter JM, Sorensen SE, Meyer AE, McGowan BD, et al. (1992) Radiofrequency gas plasma (glow discharge) disinfection of dental operative instruments, including handpieces. J Oral Implantol 18: 236-242.

39. Haertel B, Strassenburg S, Oehmigen K, Wende K, von Woedtke T, et al. (2013) Differential influence of components resulting from atmospheric-pressure plasma on integrin expression of human HaCaT keratinocytes. Biomed Res Int.

40. Aerts R, Tu X, Van Gaens W, Whitehead JC, Bogaerts A (2013) Gas purification by nonthermal plasma: a case study of ethylene. Environment Sci Technol 47: 6478-6485.

41. Isbary G, Shimizu T, Li YF, Stolz W, Thomas HM, et al (2013) Cold atmospheric plasma devices for medical issues. Expert Rev Med Devices 10: 367-377.

42. Lee FP, Wang DY, Chen LK, Kung CM, Wu YC, et al. (2013) Antibacterial nanostructured composite films for biomedical applications: microstructural characteristics, biocompatibility and antibacterial mechanisms. Biofouling 29: 295-305.

43. Benetoli LO, Cadorin BM, Baldissarelli VZ, Geremias R, de Souza IG, et al. (2012) Pyrite-enhanced methylene blue degradation in non-thermal plasma water treatment reactor. J hazard Mater 237: 55-62.

44. Ke Z, Huang Q, Zhang H, Yu Z (2011) Reduction and removal of aquous Cr (VI) by gas glow discharge plasma at the gas-solution interface. Environ Sci Technol 45, 7841-7847.

45. Rederstorff E, Fatimi A, Sinquin C, Ratiskol J, Merceron C, et al. (2011) Sterilization of exopolysaccarides produced by deeep-sea bacteria: impact on their stability and degradation. Mar Drugs 9: 224-241.

46. Magureanu M, Piroi D, Mandache NB, David V, Medvedovici A, et al. (2011) Degradation of antibiotics in water by non-thermal plasma treatment. Water Res 45: 3407-3416.

47. Yang XL, Bal MD, Han F (2010) Rapid elimination of surface organophosphorous pollutants using hydroxy radical. Huan Jing Ke Xue. 31: 1670-1674.

48. Yuan MH, Watanabe T, Chang CY (2010) DC water plasma at atmospheric pressure for the treatment of aqueous phenol. Environment Sci Technol 44: 4710-4715.

49. Rainer A, Centola M, Spadaccio C, Gheradi G, Genovese JA, et al. (2010) Comparative study of different techniques for the sterilization of poly-L-lactide electrospun microfibers; effectiveness vs. material degradation. Int J Artif Organs 33: 76-85.

50. Torress N, Oh S, Appleford M, Dean DD, Jorgensen JH, et al. (2010) Stability of antibacterial self-assembled monolayers on hydroxyapatite. Acta Biomater 6: 3242-3255.

51. Guo Y, Liao X, Ye D (2008) Detection of hydroxy radical in plasma reaction on toluene removal. J Environ Sci 20: 1429-1432.

52. Naseem A, Olliff CJ, Martini LG, Lioyd AW (2004) Effects of plasma irradiation on the wettability and dissolution of compacts of griseofulvin. Int J Pharm 269: 443-450.

53. Zhang H, Yang L, Yu Z, Huang Q (2014) Inactivation of Microcystis aeruginosa by DC glow discharge plasma; impacts on cell integrity, pigment contents and microcystins degradation. J Hazard Mater 268: 33-42.

54. Wittenburg G, Lauer G, Oswald S, Labudde D, Franz CM (2014) Nanoscale topographic changes on sterilized glass surfaces affect cell adhesion and spreaing. J Biomed Mater Res 102: 2755-2766.

55. Delgado LM, Pandit A, Zeugolis DI (2014) Influence of sterilization methods on collagen-based devices stability and properties. Expert Rev Med Devices 11: 305-314.

56. Vetten MA, Yah CS, Singh T, Gulumian M (2014) Challenges facing sterilization and depyrogenation of nanoparticles: Effects on structural stability and biomedical applications. Nanomedicine: Nanotechnology, Biology and Medicine 1000: 1391-1399.

57. Pokorny D, Slouf M, Fulin P (2012) Current knowledge on the effect of technology and sterilization on the structure, properties and longevity of UHMWPE in total joint replacement. Acta Chir Orthop Traumatol Cech 79: 213-21.

58. Popoola OO, Yao JQ, Johson TS, Blanchard CR (2010) Wear, delamination, and fatigue resistance of melt-annealed highly crosslinked UHMWPE criciate-retaining knee inserts under activities of daily living. J Orthop Res 28: 1120-1126.

59. Justan I, Tichy F, Slavicek P (2010) A new type of plasma knife and its effect on biological issue-a pilot study. Acta Chir Plast 52: 31-34.

60. Kinnari TJ, Esreban J, Zamora N, Fernandez R, Lopez-Santos CD, (2010) Effect of surface roughness and sterilization on bacterial adherence to ultra-high molecular weight polyethylene. Clin Microbiol Infect 16: 1036-1041.

61. Lleixa CJ, Grafahrend D, Klee D, Moeller M (2008) Sterilization effect on starPEG coated polymer surfaces: characterization and cell viability. J Mater Sci Mater Med 19: 1631-1636.

62. Peniston SJ, Choi SJ (2007) Effect of sterilization on the physicochemical properties of molded poly(L-lactic acid) J Biomed Mater Res B: Appl Biomater 80: 67-77.

63. McKellop H, Shen FW, Lu B, Campbell P, Salovey R (2000) Effect of sterilization method and other modifications on the wear resistance of acetabular cups made of ultra-high molecular weight polyetjhylene: A hip-simulator study. J Bone Joint Surg 82: 1708-1725.

64. Kuijpers AJ, van Wachem PB, van Luyn MJ, Plantinga JA, Engbers GH, et al. (2000) *In vivo* compatibility and degradation of crosslinking gelatin gels incorporated in knitted Dacron. J Biomed Mater Res 51: 136-145.

65. Ibrahim NA, Eld BM, Youssef MA, Ei-Sayed SA, Salah AM (2012) Functionalization of cellulose-containing fabrics by plasma and subsequent metal salt treatments. Carbohydr Polym 90: 908-914.

66. Lee JK, Choi CH (2012) Two-stage reimplantation in infected total knee arthroplasrt using a re-sterilized tibial polyethylene insert and femoral component. J Arthoplasty 27: 1701-1706.

67. Tessarolo F, Caola I, Caciagli P, Guarrera GM, Nollo G (2006) Sterility and microbiological assessment of reused single-use cardiac electrophysiology catheters. Infect Control Hosp Epidemiol 27: 1385-1392.

68. Muranyl P, Wunderlich J, Langowski HC (2010) Modification of bacterial

structures by a low temperature gas plasma and influence on packing material. J App Microbiol 109: 1875-1885.

69. Lerouge S, Wertheimer MR, Marchand R, Tabrizian M, Yahia L (2000) Effect of gas composition on spore mortality and etching during low-pressure plasma sterilization. J Biomed Mater Res 51: 128-135.

70. MacDonald D, Hanzlik J, Sharkey P, Parvizi J, Kurtz SM (2012) *In vivo* oxidation and surface damage in retrieved ethylene oxide-sterilized total knee arthroplasties. Clin Orthop Relat Res 470: 1826-1833.

71. Shen Y, Lei L, Zhang X, Zhou M, Zhang Y (2008) Effect of various gases and chemical catalysts on phenol degradation pathways by pulsed electrical discharges. J Hazard Mater 150: 713-722.

72. Kvam E, Davis B, Mondello F, Garner AL (2012) Nonthermal atmospheric plasma rapidly disinfects multidrug-resistant microbes by inducing cell surface damage. Antimicrob Agent Chemother 56: 2028-2036.

73. Whittaker AG, Graham EM, Baxter RL, Jones AC, Richardson PR, et al. (2004) Plasma cleaning of dental instruments. J Hosp Infect 56: 37-41.

74. Yuen PK, Su H, Gorai VN, Fink KA (2011) Three-dimentional interconnected microporous poly(dimethylsiloxane) microfluidic devices. Lab Chip 11: 1541-1544.

75. Gatineau M, El-Warrak AO, Bolliger C, Mourez M, Berthiaume F (2012) Effects of sterilization with hydrogen @eroxide gas plasma, ethylene oxide, and steam on bioadhesive properties of nylon and polyethylene lines used for stabilization of canine stifle joint. Am J Vet Res 73: 1665-1669.

76. Gao J, Yu J, Li Y, He X, Bo L, et al. (2006) Decoloration of aqueous Brilliant Green by using glow discharge electrolysis. J Hazard Mater 137: 431-436.

77. Zhang RB, Wu Y, Li GF, Wang NH, Li J (2004) Plasma induced degradation of indigo Carmine by bipolar pulsed dielectric barrier discharge (DBD) in the water-air mixture. J Environ Sci 16: 808-812.

78. Liu YC, Han KY, She TC (2004) Construction of a low-pressure microwave plasma reactor and its application in the treatment of volatile organic compounds. Environ Sci Technol 38: 3785-3791.

79. Kim K, Kim C, Byun Y (2004) Biostability and biocompatibility of surface-grafted phospholipids monolayer on a solid substrate. Biomaterials 25: 33-41.

80. Chin JY, Moon KW, Park JK, Park DJ (2013) Development of reactive artificial liner recycled materials. 1. Mechanical properties and chemical compatibility. Waste Manag Res 31: 706-713.

81. Strickler F, Richard R, McFadden S, Lindquist J, Schwarz MC, et al. (2010). *In vivo* and *in vitro* characterization of poly(stylene-β-osobutylene-β-stylene) copolymer stent coating for biostability. Vascular compatibility and mechanical integrity. J Biomed Mater Res *92*, 773-782.

82. Lin SY, Lee CJ, Lin YY (1991) The effect of plasticizers on compatibility, mechanical properties, and adhesion strength of drug-free Eudragit E films. Pharm Res 8: 1137-1143.

83. Gentis ND, Vranic BZ, Betz G (2013) Assessing compressibility and compactibility of powder formulations with Near-Infrared Spectroscopy. Pharm Dev Technol 18: 156-171.

84. DeHoff PH, Anusavice KJ (2009) Viscoelastic finite element stress analysis of the thermal compatibility of dental bilayer ceramic systems. Int J Prosthodont 22: 56-61.

85. Fisher J, Stawarczyk B (2007) Compatibility of machined Ce-TZP/Al_2O_3 nanocomposite and a veneering ceramic. Dent Mater 23: 1500-1505.

86. Kunze C, Freier T, Helwig E, Sandner B, Reif D, et al. (2003) Surface modification of tricalcium phosphate for improvement of the interfacial compatibility with biodegradable polymers. Biomaterial 24: 967-974.

87. Niederer PF, Kaeser R, Walz FH, Brunner A, Faerber E (1995) Compatibility considerations for low mass rigid-belt vehicles. Accid Anal Prev 27: 551-560.

88. Mishra S, Viano A, Fore N, Lewis G, Ray A (2003) Influence of lamella features of UHMWPE on its physical and uniaxial tensile properties. I. Effect of sterilization method in uncrosslinked and unaged materials. Biomed Mater Eng 13: 135-146.

89. Vollpracht A, Brameshuber W (2010) Investigation on the leaching behavior of irrigated construction elements. Environ Sci Pollut Res Int 17: 1177-1182.

90. Bouvet M, Francois D, Schwartz C (2007) Road soil retention of Pb leached from MSWI bottom ash. Waste Manag 27: 840-849.

91. Van der Sloot HA, Hoede D, Cresswell DJ, Barton JR (2001) Leaching behavior of synthetic aggregates. Waste Manag 21: 221-228.