Weibull Analysis to Evaluate the Lifetime of Dental Implants

Viresh Sharma
Department of Mathematics, N.A.S (PG) College, Meerut, India,
Email : vireshsharma1@yahoo.com

ABSTRACT- A product's lifespan can be predicted using Weibull analysis. Because it enables predictions based on a small sample of data from experiments or field trials, this statistic is helpful. Weibull analysis was used to fit the sample data to a Weibull distribution. The chance of survival can be calculated at any moment if the data are fitted to a Weibull distribution. In order to provide several solutions to the issues below, we apply this analysis to the lifetime assessment of dental implants in this study:

i. When do dental implants begin to deteriorate?
ii. How long should a dental implant warranty last?
iii. Do dental implants demonstrate early failure (such as infant mortality)?
iv. Are dental implants prone to failure at random over time, or are failure traits more closely linked to wear?
v. When do the majority of dental implants fail?

Keywords: Weibull Distribution, Probability Density Function, Dental Implants, Reliability Function

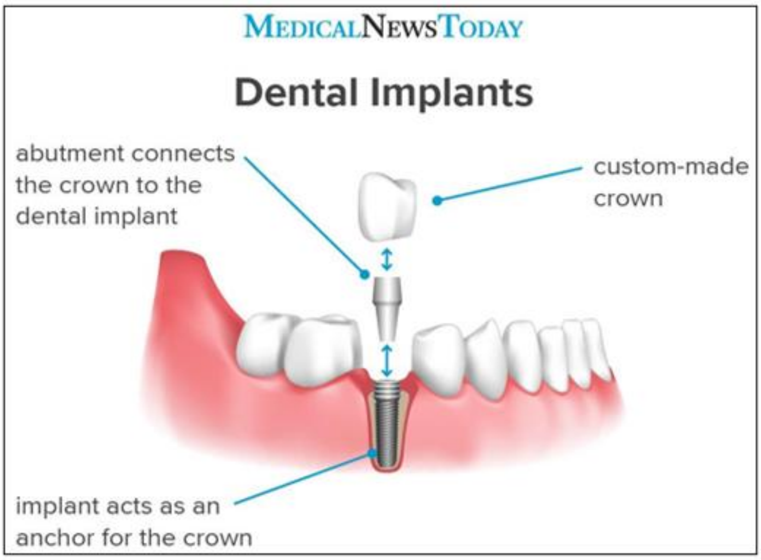
Tob Regul Sci. ™ 2021 ;7(6-2): 94-102
DOI: doi.org/10.18001/TRS.7.6.2.10

INTRODUCTION

Phase stress analysis was put to the test by **M. Borbaet al. (2013)** to see if it could predict how reliable an alumina-based dental ceramic (VITA In-Ceram AL blocks) would be after being put through a mechanical ageing test. **M. V. Swaim (2014)** took into account the mechanical strength loss, zirconia phase changes, and water's potential to cause dental ceramics to dissolve. **G. Khatibi et al. (2015)** used an ultrasonic resonance fatigue testing equipment to examine the high cycle fatigue behavior of CoCr L605 thin wall tubes. According to the study, the tubes showed a high level of fatigue, and their fatigue lives were much lower than those of tubes constructed of other materials. According to research by **Zahra Abbasi et al. (2015)**, several glass-ceramic and dental bioactive material combinations can be successfully manufactured using the sol-gel process. The influence of zirconia stabilization degree (CeO_2 levels between 10.0 and 11.5 mol%) on the variability and mechanical characteristics of Ce-TZP-Al_2O_3-$SrAl_{12}O_{19}$ materials has been examined by **H. Reveron et al. (2017)**.By using finite element analysis, **Y. Duan et al. (2018)**assessed the fatigue life of a dental implant system with a smaller diameter. They discovered that the device described by ISO 14801 is an accurate gauge of the fatigue life of the implant system after testing physical samples of the implant utilizing the Accelerated Life Testing (ALT) technique. Validation in 3D (FEA) was anticipated. **Kim S. H. & Choi Y. S.'s (2019)** study sought to assess and contrast how several properties of monolithic and conventional zirconia changed over the course of hydrothermal ageing. In a sense, people have been debating the question of "to be or not to be" for ages. There is no conclusive response because there are numerous variables involved.

DENTAL IMPLANTS

Dental implants are artificial components that a dentist puts in the jawbone to replace missing teeth. You might require dental implants to replace any missing teeth.



A prosthesis that helps to replace a missing tooth is one that uses dental implants. The implant is placed in the jawbone using screws, and the crown is then attached to it. An abutment is a piece of equipment that joins the dental implant to the artificial tooth. This crown is made to fit a person's mouth and complement their teeth's hue. Veneers mimic the appearance, feel, and functionality of real teeth. Although dentures are a less intrusive tooth replacement alternative, implants provide various benefits. Compared to dentures, they are more durable and endure longer. Implants have a greater success rate than conventional dental implants and are more pleasant and natural-looking. Additionally, implants enhance chewing efficiency and lower the chance of cavities developing in nearby teeth.They may also result in greater bone restoration where the tooth formerly was, which may lessen the sensitivity of the teeth next to it. The implant doesn't need to be taken out and cleaned every night. Not everyone should get dental implants because they need surgery and might be pricey. Your jawbone must be sound prior to implant placement surgery.

WEIBUL ANALYSIS

Weibull shape parameter, β, and characteristic lifetime, η, were estimated using the data. Reliability and risk level can be evaluated using β and η at a particular time (x).A popular model for simulating different failure distributions is the Weibull distribution. Based on the reliability function, risk rate, and Weibull distribution probability density function with two parameters:

Probability Density Function: $f(t) = \left(\frac{\beta}{\eta}\right)\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}}$

Reliability Function: $R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$

Hazard Rate: $h(t) = \left(\frac{\beta}{\eta}\right)\left(\frac{t}{\eta}\right)^{\beta-1}$

The location parameter, commonly referred to as the failure-free life, is another component of the three-parameter Weibull distribution. In these scenarios, t in the equation above is changed to t-δ.

The moment when 63.2% of the population dies is what defines life. A Bezier curve always produces a smooth curve, no matter the shape parameter. Here are some figure parameters:

β = 1.0 : Exponential distribution, constant failure rate

β = 3.5 : Normal distribution (approximation)

β < 1.0 : Decreasing failure (hazard) rate

β > 1.0 : Increasing failure (hazard) rate

Median ranks are calculated using the following equation:

Median Rank Equation: $F(t) = \frac{j-0.3}{n+0.4}$

where: j is the failure order, n is the sample size

Test data failures are labeled as **"managed"** or **"waiting"** data. To determine F(t), the cumulative fraction failed, for this type of data, a modified ranking or ordered score is computed. The rank j is changed in the median rank equation so that the median is the point at which the rank is divided in half. **The following equation is used to determine the increase: Increment Equation:** $\boldsymbol{I_j = \frac{(n+1)-O_p}{1+c}}$

where:

I_j is the increment for point j.

n is the total number of records, both failures and censored items.

O_p is the order of the previous point, or record.

c is the number if remaining points, including the current point.

The order of each point, O_j, is the order of the previous point, O_p, plus $I_j$calculated according to the above equation.

WEIBULL ANALYSIS TO EVALUATE THE LIFETIME OF DENTAL IMPLANTS

We understand this analysis with the help of the following numerical:

NUMERICAL

The likelihood of the surgery failing between the time of implant placement and 10 hours is relatively high. Between 10:00 a.m. and 10:00 p.m., eleven accidents happened. The "s" in the second column of the final input line denotes that, after 50 hours, neither the implant nor the operation has failed. The analysis is predicated on the notion that failure happens at the conclusion of the time period. It is more accurate to enter intermediate times for that period if crashes happen inside that time frame (eg. change the first four times to 5, 15, 25, and 35).

10 f g 1
20 f g 11
30 f g 28
40 f g 45
50 s g 8

Given that time-to-failure are: 20 f, 42 s, 50 f, 78 f, 83 s, 89 s, 102 f, 139 f .

Plot Weibull, F(t), R(t), f(t), h(t) & Failure timeline. Use the Rank Regression on Y (RRY) and Rank
Regression on X (RRX) parameters and salient points. Also give its summary table for 95% confidence level.

Solution: Parameter estimates based on linear regression (Rank Regression on Y (RRY), Rank Regression on X (RRX):

Table 1: Parameter estimates based on linear regression (Rank Regression on Y (RRY), Rank Regression on X (RRX)

Parameter	RRY	RRX
Shape parameter (β)	1.49	1.53
Characteristic life (η)	114.74	112.69
Coefficient of determination (r^2)	0.97	0.97
Mean life (μ)	103.70	101.47
Variance (σ^2)	5,047.09	4,558.14

Parameter estimates based on Maximum Likelihood Estimation (MLE):

Table 2: Parameter estimates based on Maximum Likelihood Estimation (MLE)

Parameter	Lower 95.0% Confidence Limit	Point Estimate	Upper 95.0% Confidence Limit
Shape parameter (β)	1.10	2.24	4.55
Characteristic life (η)	70.57	104.53	154.83
Mean life (μ)		92.58	
Variance (σ^2)		1,916.33	

Sample size ≤ 50 &Confidence intervals based on Binomial Exact Method. All plots are based on parameters derived from linear regression, Rank Regression on Y method (RRY). This method is commonly used for sample sizes of 15 or less.

Table 3

Time (Hours)	Failures LCL@95%	Expected Failures for a Sample of 8	Failures UCL@95%	F(t) LCL@95.0% %	F(t) %	F(t) UCL@95.0% %	R(t) LCL@95.0% %	R(t) %	R(t) UCL@95.0% %
0.00	0.0	0	2.5	0.0	0.0	31.23	68.77	100.0	100.0
29.59	0.03	1	4.21	0.32	12.5	52.65	47.35	87.5	99.68
49.60	0.25	2	5.21	3.19	25.0	65.09	34.91	75.0	96.81
69.02	0.68	3	6.04	8.52	37.5	75.51	24.49	62.5	91.48
89.65	1.26	4	6.74	15.7	50.0	84.3	15.7	50.0	84.3
113.25	1.96	5	7.32	24.49	62.5	91.48	8.52	37.5	75.51
142.96	2.79	6	7.75	34.91	75.0	96.81	3.19	25.0	65.09
187.82	3.79	7	7.97	47.35	87.5	99.68	0.32	12.5	52.65
421.41	5.5	8	8.0	68.77	99.9	100.0	0.0	0.1	31.23

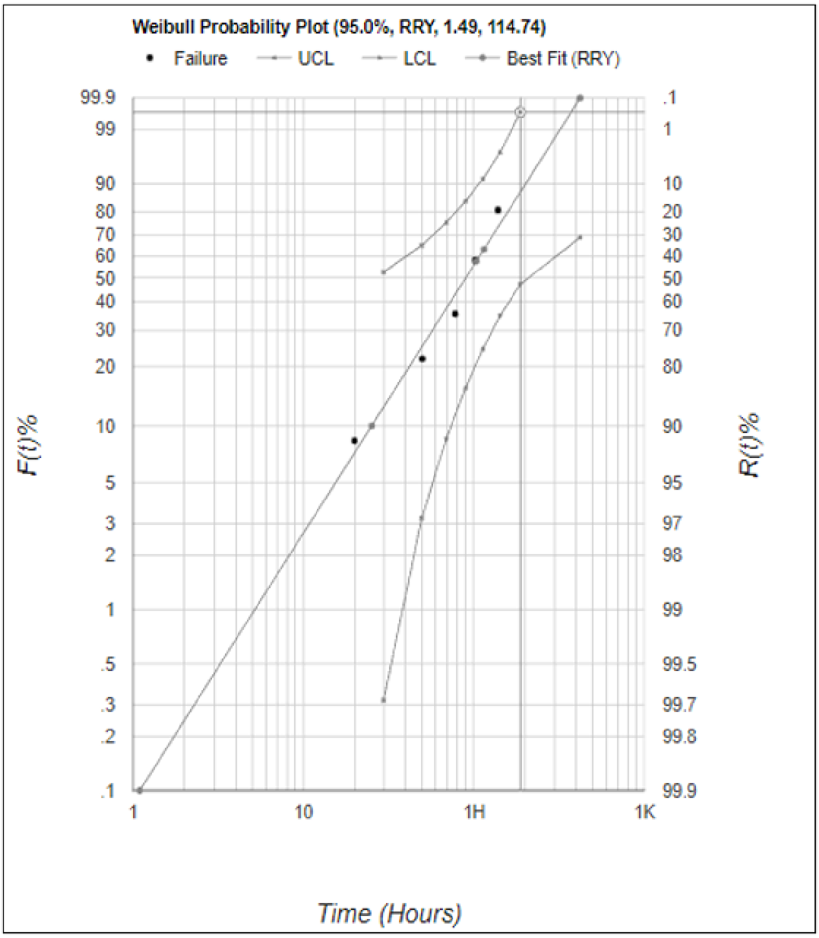


Figure 1: Weibull Probability Plot

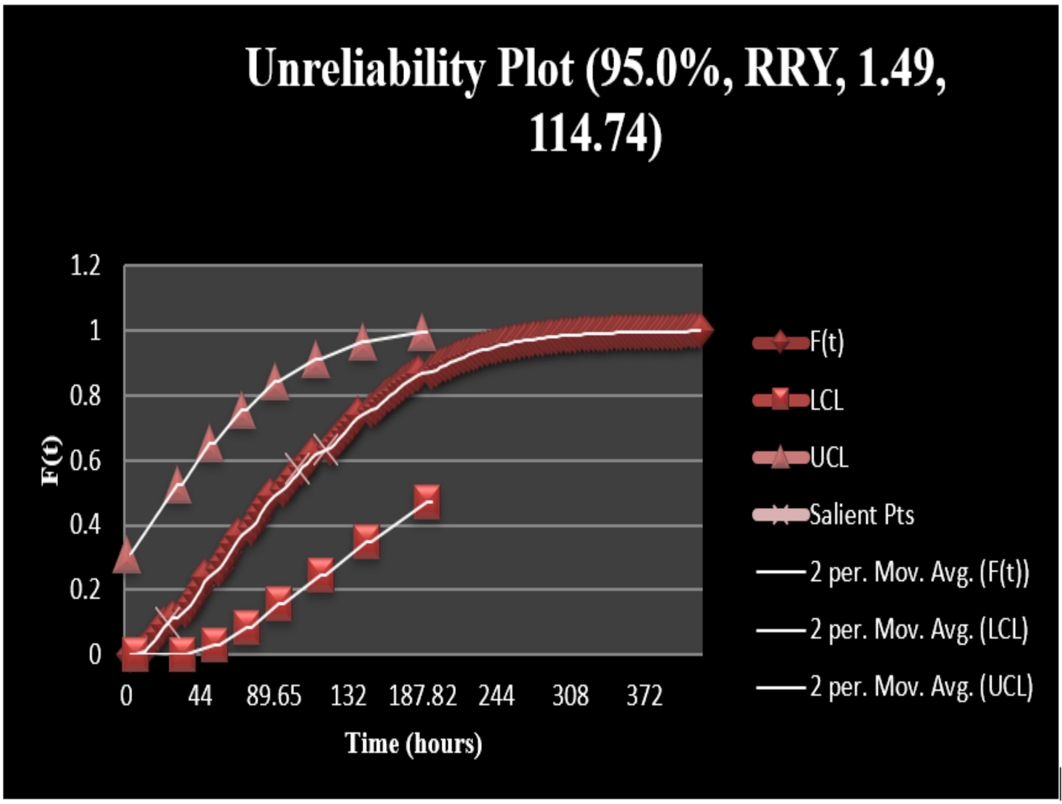


Fig 2: Unreliability Plot

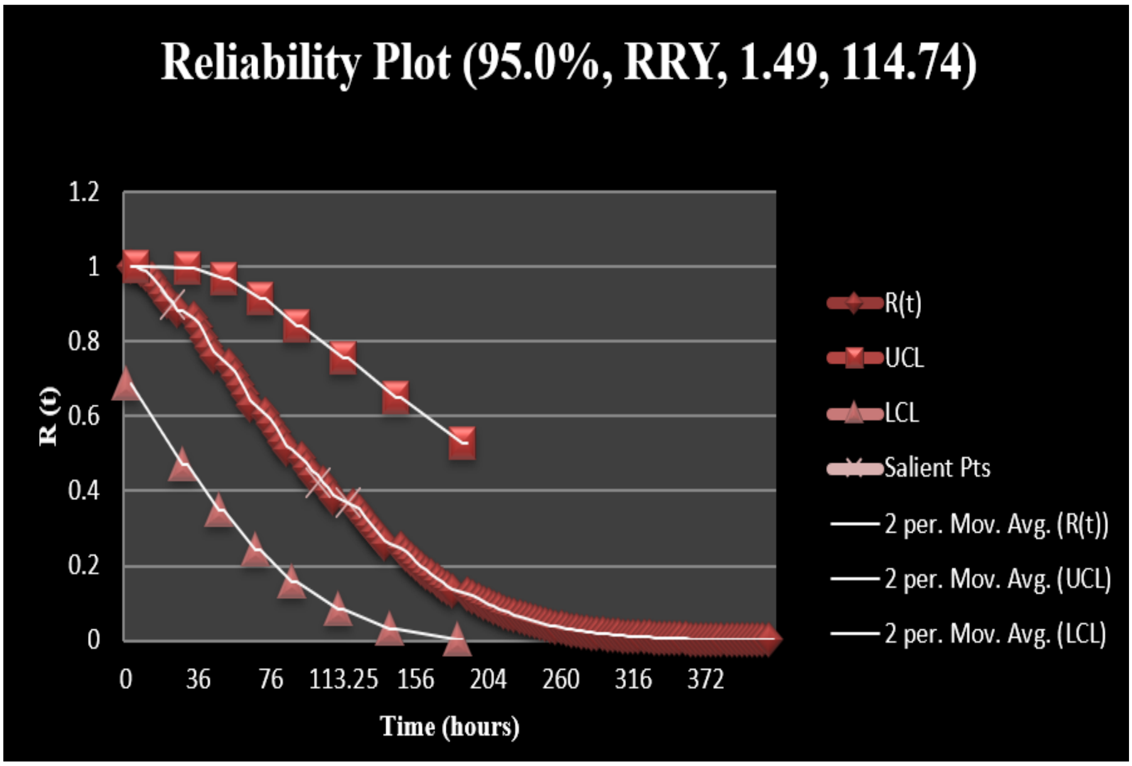


Fig 3: Reliability Plot

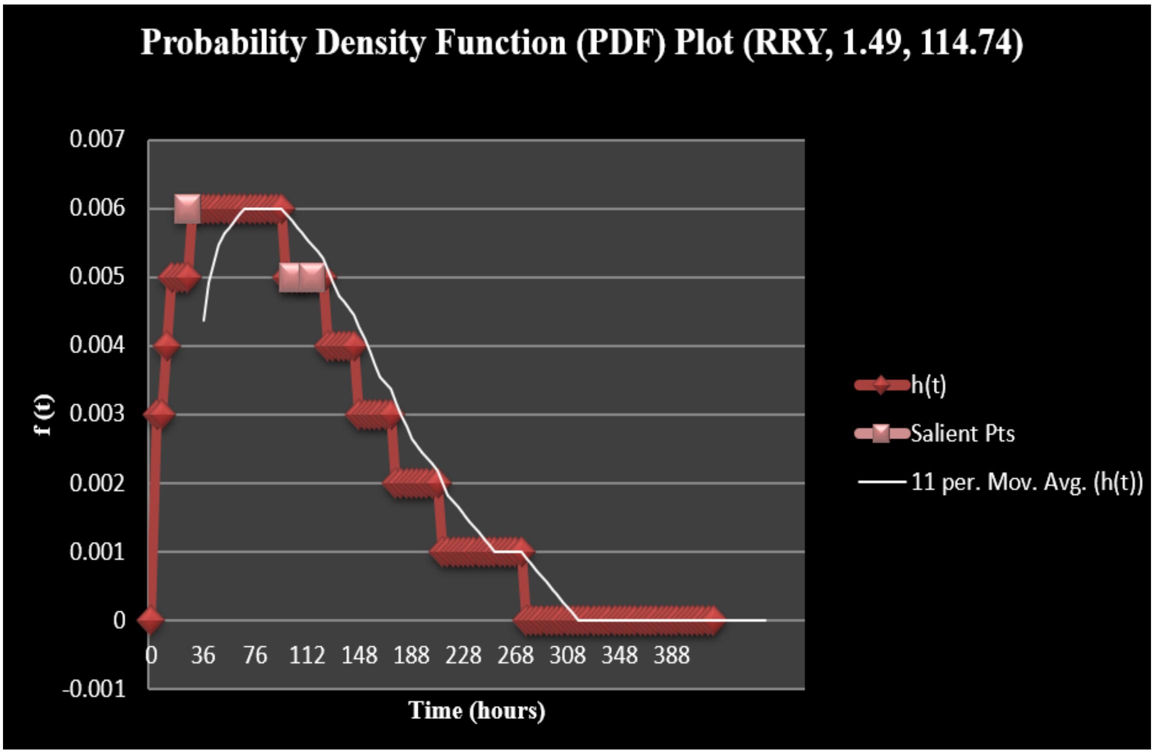


Fig 4: Probability Density Function Plot

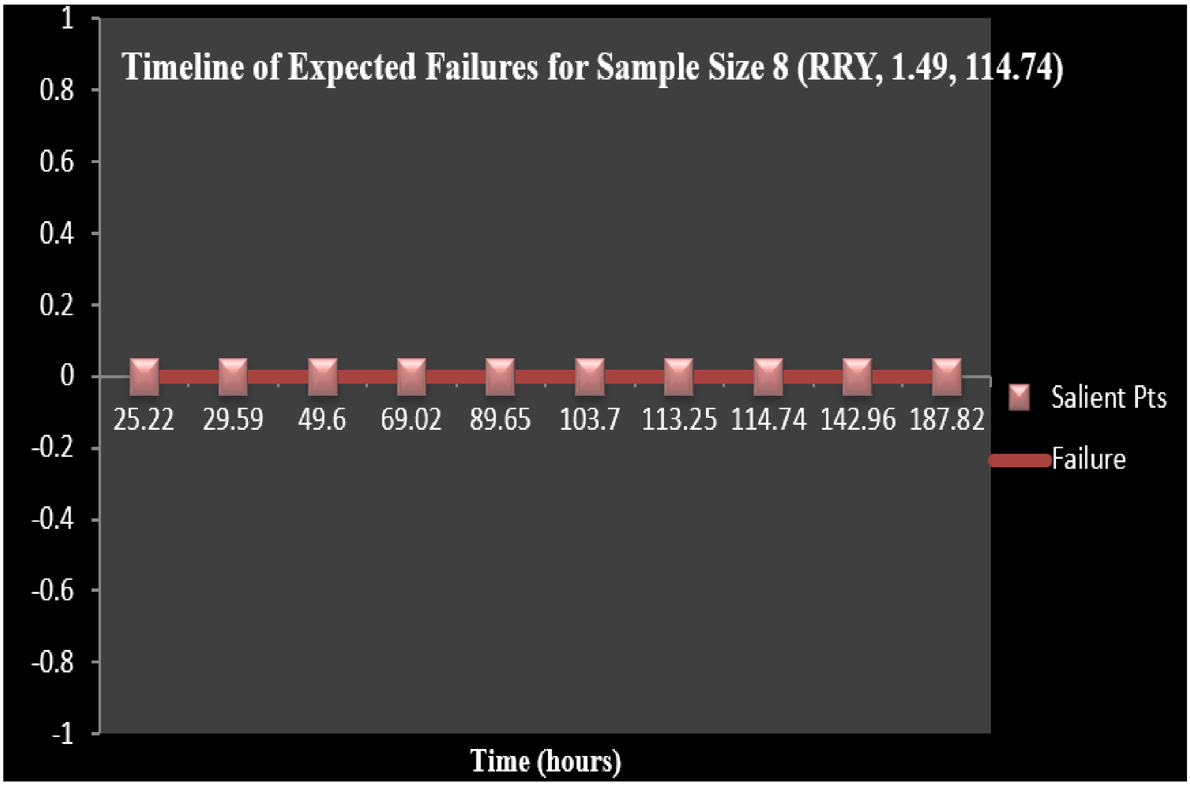


Fig 5: Timeline of Expected Failures for Sample size 8

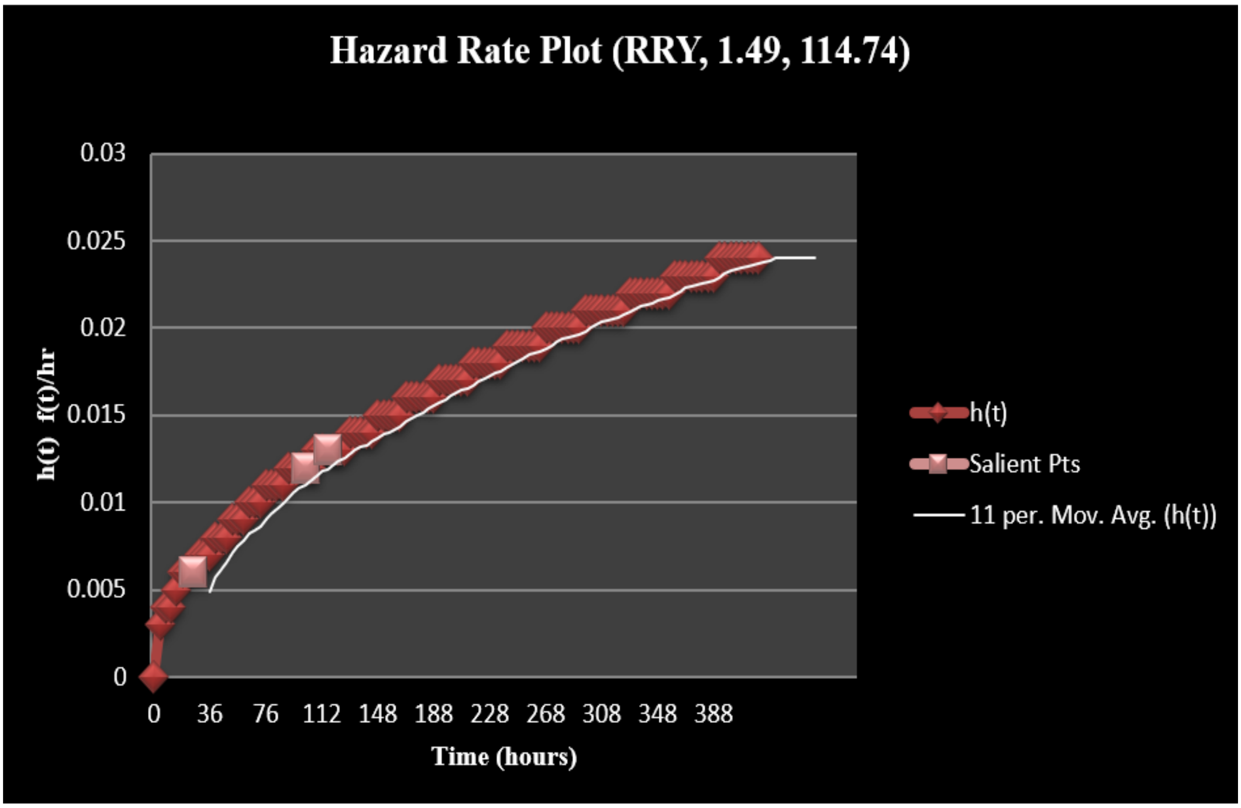


Fig 6: Hazard Rate Plot

CONCLUSION

Only by seeing the evaluated tables and graph we are able to get the answer of our all questions that are mentioned in the abstract of the paper. So, Weibull analysis plays an important role in the analysis of dental implants and we should first do this analysis and then start the work of dental implantation to overcome future problem.

REFERENCES

[1] **Abbasi Z., Bahrololoum M. E., Bagheri R., Shariat M. H. (2016)**: "Characterization of the bioactive and mechanical behavior of dental ceramic/sol–gel derived bioactive glass mixtures", Journal of the Mechanical Behavior of Biomedical Materials, 54: 115-122.

[2] **Borba M., Cesar P. F., Griggs J. A., Bona A. D. (2013)**: "Step-stress analysis for predicting dental ceramic reliability", Dental Materials, 29(8): 913-918.

[3] **Duan Y., Gonzalez J. A., Kulkarni P. A., Nagy W. W., Griggs J. A. (2018):** "Fatigue lifetime prediction of a reduced-diameter dental implant system: Numerical and experimental study", Dental Materials, 34(9):1299-1309.

[4] **Khatibi G., Lederer M., Kotas A. B., Frotscher M., Krause A., Poehlmann S. (2015):** "High-cycle fatigue behavior of thin-walled CoCr tubes", International Journal of Fatigue, 80: 103-112.

[5] **Kim S. H. &Choi Y. S. (2019):** "Changes in properties of monolithic and conventional zirconia during aging process", Mechanics of Materials, 138:103159.

[6] **Reveron H., Fornabaio M., Palmero P., Fürderer T., Adolfsson E., Lughi V., Bonifacio A., Sergo V., Montanaro L., Chevalier J. (2017)**: "Towards long lasting zirconia-based composites for dental implants: Transformation induced plasticity and its consequence on ceramic reliability", Acta Biomaterialia, 48: 423-432.

[7] **Swain M. V. (2014)**: "Impact of oral fluids on dental ceramics: What is the clinical relevance?",Dental Materials, 30(1): 33-42.