RESEARCH & DEVELOPMENT

Setting Appropriate Benefit/Condition Jumps for Pavement Treatments in PMS

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16. Abstract

This research was conducted to determine pavement performance jumps after treatment, which are defined as the difference between pre-treatment and post-treatment Pavement Condition Rating (PCR) values. The North Carolina Department of Transportation (NCDOT) resets the PCR of sections to its highest value of 100 after a treatment is applied. However, the condition of a pavement after treatment depends on the treatment applied, indicating that the PCR after treatment can be less than 100. This research was conducted to investigate the magnitudes of pavement performance jumps caused by most common types of treatment utilized by the NCDOT. The data for this research was collected by windshield surveys, and it was divided into treatment. Pre-treatment and post-treatment PCR values were calculated to determine the performance jumps, and after-treatment performance curves were developed. These jumps along with the performance curves can provide better prediction of the pavement condition over its life after a treatment is applied and assist NCDOT engineers in developing effective treatment plans.

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EXECUTIVE SUMMARY

Pavement condition improves, or its performance rating jumps, after a pavement receives a preservation or rehabilitation treatment. The Pavement Condition Rating (PCR) used by the North Carolina Department of Transportation (NCDOT) is a composite index which represents a consolidated condition of various types of surface distresses. PCR ranges from 0 to 100, with a higher score representing a better performance condition. An appropriate treatment can effectively eliminate distresses from the surface layer, resulting in a post-treatment PCR (Post_PCR) of 100. Currently in North Carolina, the Post_PCR is set as 100, meaning that the pavement surface has been restored to a perfect condition. This practice is not invalid since it has been observed in other PMSs as engineering judgment plays a significant role in such systems. Research, however, has shown that this improvement, or performance jump, depends on a number of factors including the type of treatment applied. This indicates that the PCR value after treatment might be less than 100. This research was conducted to investigate the magnitudes of pavement performance jumps caused by most common types of treatment utilized by the NCDOT.

Setting a different value for the post-treatment PCR value other than 100 will help NCDOT engineers make effective decisions, as the pavement condition can drop to the treatment threshold quicker. For example, a drop from 92 to 60 is quicker than a drop from 100 to 60. Keeping this in mind, the decision makers can recommend the most appropriate pavement preservation strategy based on the treatments being applied and the benefit they provide in terms of performance jump. It will also enable engineers to predict the performance of pavements more accurately using the post-treatment performance curves developed during this study.

In this study, the performance jump is defined as the difference between pre-treatment performance values and the post-treatment performance values. Windshield data was used because the volume of repeated automated measurements of PCR was not sufficient to adequately calculate performance jumps for all families of pavements. To determine performance jumps, the roadway sections with performance jumps were identified and their age reset to zero, and their performance models were developed to model the PCR value after treatment. Additionally, after-treatment performance curves were developed. These curves were compared with performance curves before treatment to identify differences in performance.

To gain the largest treatment benefit, the ideal pretreatment PCR values were also determined using Cost-Benefit Analysis (CBA) and regression analysis.

Based on the study of 56 roadway treatment families, the following conclusions have been drawn:

- In North Carolina, *AC Construction/Reconstruction*, *Chip Seal*, *Mill + Resurface*, and *Resurface* are the most commonly applied treatments for ASP pavements; and *JCP Construction / Reconstruction, JCP Minor Rehabilitation*, and *Unbonded Concrete Overlay (UBC)* for JCP pavements.
- Post-treatment ASP performance curves' intercepts are, in descending order, 92.8, 90.0, 87.8, and 84.6 for *AC Construction/Reconstruction, Resurface, Mill + Resurface,* and *Chip Seal*, respectively.

- In descending order, average performance jumps of ASP treatments are 28.7, 28.3, 27.9, and 26.0 for *AC Construction/Reconstruction*, *Resurface*, *Mill + Resurface*, and *Chip Seal*, respectively.
- Among 4 ASP treatments, *AC Construction / Reconstruction* has the largest benefit, followed by *Mill+Resurface* and *Resurface*, and *Chip Seal* has the smallest benefit.
- To obtain the highest treatment benefit, the best timing to applying ASP treatments are: for *Chip Seal*, when Pre_PCR value is 53.98; for *Mill+Resurface*, when the Pre_PCR value is 50.49. It seems that if one of these two treatments has been selected, deferring treating NC pavements by one year might ease budget constraints and still have a slight benefit gain. It should be noted, however, that roadways that are not treated on time can cause safety issues, affect public perception and the overall network performance. Therefore, it is essential that engineers need to carefully evaluate pros and cons associated with each option before making the final maintenance decision.
- Except for *Chip Seal*, all other ASP treatment curves follow the same deterioration trend: parallel and then rejoin the original performance curves. For *Chip Seal*, the treatment curve quickly rejoins the original curve and then stays below it. This means that *Chip Seal* curve quickly under-performs the original curve.

Recommendations for avenues of further research are highlighted below:

- It is recommended to combine *Mill + Resurface* and *Resurface* data and study their performance in a future study. *Mill + Resurface* is a more intensive treatment than *Resurface*, its performance, according to the results of this study, however, was worse than *Resurface.* It is possible that the decision of using *Mill + Resurface* was made not based on distress severities, but for maintaining geometric and operational features of curb and gutter. Therefore, data of these two treatments probably should be combined and studied again.
- It is recommended to use the average Pre_PCR values determined in this study to define pretreatment conditions for future performance models. Pretreatment condition can significantly impact pavement performance. One way to include pretreatment condition in the performance evaluation process is to include it as a grouping factor when develop performance models. For example, the US 0-5k family can be divided into two sub-families based on Good/Poor pretreatment condition: US 0-5k /Good and US 0-5k /Poor, and these family models can be developed to more accurately predict pavement performance. In this process, the average Pre_PCR values determined in this study can be used as thresholds to define Good and Poor conditions.
- It is recommended that the influence of other factors associated with treatments be considered. This study focused on the dominant types of treatments applied, and future studies may focus on the materials used in these treatments, the thicknesses of overlays, and the effects of combinations of potential factors.

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CHAPTER 1 INTRODUCTION

1.1 Background

This research was conducted to determine pavement performance jumps after treatment for the North Carolina Department of Transportation (NCDOT). In this study, the performance jump is defined as the difference between pre-treatment performance values and the post-treatment performance values.

The NCDOT Pavement Management System (PMS) measures the performance of a pavement section in terms of Pavement Condition Rating (PCR), whose value ranges from 0 to 100. A PCR of 100 denotes that the pavement is free of any distresses. NCDOT resets the value of PCR to 100 after a treatment is performed, effectively inducing an improvement of performance. This practice is not invalid since it has been observed in other PMSs as engineering judgment plays a significant role in such systems (Khattak and Baladi 2015). However, research has shown that this improvement, or performance jump, depends on a number of factors including the type of treatment applied (Dean and Baladi 2013). This indicates that the post-treatment PCR value might be less than 100.

Setting a different value for the post-treatment PCR value other than 100 will help NCDOT engineers make effective decisions, as the pavement condition can drop to the treatment threshold quicker. For example, a drop from 92 to 60 is quicker than a drop from 100 to 60. Keeping this in mind, the decision makers can recommend the most appropriate pavement preservation strategy based on the treatments being applied and the benefit they provide in terms of performance jump. It will also enable engineers to predict the performance of pavements more accurately using the post-treatment performance curves developed during this study. This is because the deterioration of a pavement section changes once it is treated.

1.2 Purpose and Scope

The goal of this research was to determine the performance jumps of the most common types of treatment utilized by the NCDOT. Windshield data was preferred over automated data because the volume of repeated automated measurements of PCR was not sufficient to adequately calculate performance jumps for all families of pavements.

1.3 Research Approach

To achieve this goal, the sections with performance jumps were identified and their age reset to zero, and performance models were developed to model the PCR value after treatment. Additionally, after-treatment performance curves were developed. These curves were compared with performance curves before treatment to identify differences in performance. To gain the largest treatment benefit, the ideal pretreatment PCR values were also determined. The data being analyzed included treatment history and pavement condition data based on the windshield survey collection method for asphalt (ASP) and concrete (JCP) pavements.

1.4 Organization of the Report

Chapter 1 provides the background of the study and lays out the research goals and objectives. Chapter 2 is a comprehensive review of the literature available on performance jumps and other relevant topics. The methodology of this research is shown in detail in Chapter 3, and the findings and conclusions are presented and discussed in Chapter 4. Finally, Chapter 5 presents recommendations for future research, and an implementation and technical transfer plan is included in Chapter 6.

CHAPTER 2 LITERATURE REVIEW

A comprehensive literature review was conducted to summarize the findings from previous studies that are relevant to this study.

2.1 Pavement Performance

Pavement performance is a measure of how pavements change their condition or serve their intended function with accumulating use (Lytton 1987). Pavement performance measurements are the basis of pavement performance models. Highway agencies all over the country have different methods to measure the condition of their pavements and model the performance. International Roughness Index (IRI) and rut depth (RUT) are among the performance indicators collected regularly by the agencies (Irfan et al. 2009).

In addition to IRI and RUT, a well-documented method of measuring pavement performance is the Pavement Condition Index (PCI). PCI is a composite index which is based on the information about distress type, severity, and extent observed in the field (AASHTO 2012). It is calculated by subtracting deduct points from a perfect score of 100 where the deduct points are assigned based on the type, severity, and extent of the distresses of pavement sections visually surveyed. (AASHTO 2012). There are two methods by which pavement sections are surveyed (Findley et al. 2011):

1. The traditional manual method which involves trained personnel making observations by slowly walking or driving on the road
2. Automated data collection process which utilizes vehicles mounted with cameras and other observational equipment

2.2 Pavement Condition Rating

NCDOT relies on a composite index called Pavement Condition Rating (PCR) to measure the condition of its pavements. It is a point-based matrix system that deducts points depending on the amount of distresses on the roadway. The matrix starts with a value of 100 for a perfect roadway, and deductions are made based on the severity levels observed in the field. These deduction values have been derived by the NCDOT engineers based on their years of experience.

An index like the PCR must be designed to transfer real distress data to a scalar that can be used to express the health of the network (Baladi et al. 2011). In this regards, the NCDOT publishes a manual for the surveys which outlines the method to measure the type of the distress, as well as the severity in categories of low, medium, or high. Deduct values are assigned based on the categories of severity (NCDOT 2011).

NCDOT collects pavement performance data using windshield surveys as well as automated surveys adopted recently. According to Corley-Lay et al. (2010), North Carolina surveys 100% of its flexible pavements and a 20% sample of each rigid pavement on a 2-year cycle. Starting in 2010, all pavements have been surveyed annually at a 100% rate.

This study focuses on the data collected using the manual method, also referred to as the windshield survey method. The reason is that the sufficient quantity and construction history of the windshield data makes it a better data source than the automated data.

2.3 Treatment Effectiveness and Performance Jumps

Whenever the condition of a pavement section falls below a predefined threshold, a treatment is applied to rehabilitate the section. These treatments can be categorized as preventive maintenance or corrective maintenance (Haas et al. 1994). Preventive maintenance is performed to maintain a section's performance above the threshold whereas corrective maintenance is aimed at sections which have fallen below an acceptable condition.

A treatment is assumed to repair or restore the pavement condition, or performance, to a level substantially higher than the pre-treatment level (Rajagopal and George 1990). One method of determining treatment effectiveness is determining the area under the pavement condition versus time curve, where a large area indicates greater effectiveness (Mamlouk and Zaniewski 1998). The improvement in the remaining service life of a pavement section after a treatment is applied is another measure of treatment effectiveness (Amador-Jiménez and Afghari 2015; Baladi et al. 2011).

Labi and Sinha (2003) have termed performance jumps as another measure of treatment effectiveness in the short term for individual treatments, as opposed to long term effectiveness which can be determined by evaluating multiple treatments applied over a pavement life cycle. In another study, Labi and Sinha (2003) have stated that the performance jump is simply the vertical, or instantaneous elevation in the performance or condition of a pavement due to maintenance. As an indicator of treatment effectiveness, performance jumps can be used to select an optimal treatment for pavement distresses from the available alternatives as well as to optimize the timing for treatment applications (Haider and Dwaikat 2011; Wang et al. 2011). It can also be used to measure the cost effectiveness of treatments applied (Irfan et al. 2009).

In this study, the performance jump, or condition jump, is defined as the difference between pre-treatment PCR values (the PCR values right before treatment, i.e., Pre_PCR) and the post-treatment PCR values (the predicted PCR values right after treatment, i.e., Post_PCR). Figure 1 shows the performance jump at age 'n' due to treatment.

2.4 Previous Studies on Performance Jumps

In their paper, Labi and Sinha (2003) included examples of studies on calculation of performance jumps for different treatments in pavement preservation. In an attempt to study the economic benefits of preventive maintenance treatments, Al-Mansour and Sinha (1994) studied the gain in Pavement Serviceability Index (PSI) as a result of seal coating in Indiana by comparing the pre-treatment and post-treatment PSI within one year of the treatment being applied. The PSI ranges from 1 to 5 with 5 being the highest value. They concluded that a pavement should not be allowed to deteriorate beyond a PSI of 3 to achieve the maximum benefits in terms of performance and costs.

Labi and Sinha (2003) on the other hand defined performance jumps as a measure of short term effectiveness of pavement treatments and compared them with two other effectiveness measures: Deterioration Reduction Level (DRL) and Deterioration Rate Reduction (DRR). They argued that relative timing between pavement maintenance and performance survey is vital in the computation of short-term effectiveness, and they derived expressions based on these relative scenarios as a prelude to the overall process of maintenance effectiveness evaluation.

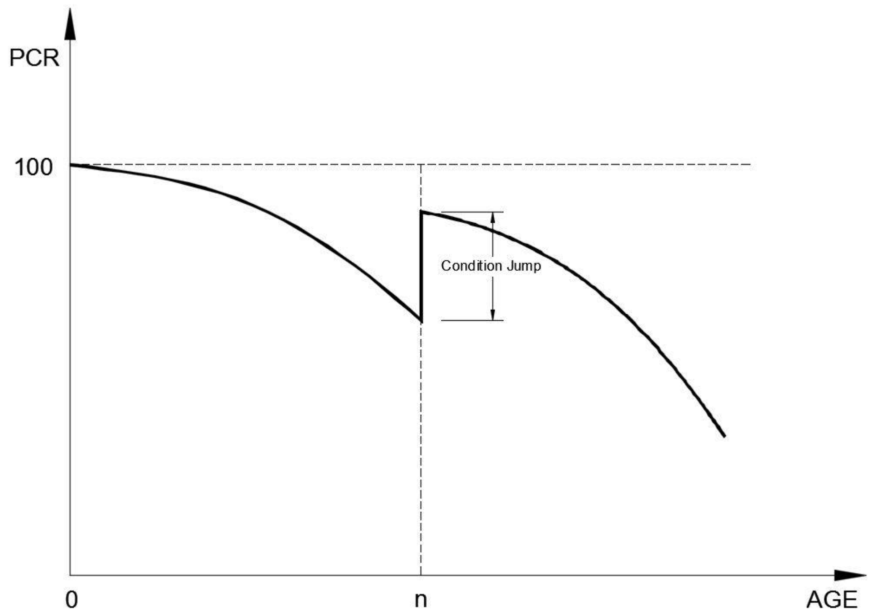

Figure 1: Pavement Performance Curve with a Condition Jump

Building on the previously mentioned study, Labi et al. (2007) used performance jumps in RUT, IRI, and PCR and developed a method to measure the effectiveness of microsurfacing treatements for roadway sections in Indiana. Their study showed the immediate benefits of microsurfacing in all three performance measures, with PCR showing an increase of 3-9 units. Similarly, performance jumps of resurfacing treatments were calculated to demonstrate treatment effectiveness and cost effectiveness using pavement data in Tennessee (Qiao et al. 2011). In both studies, performance jumps were considered as an appropriate measure of short term effectiveness of treatments, however the treatments analyzed were surficial in nature.

Bao et al. (2010) calculated the performance jumps for two treatments: minor leveling and in-situ stabilization. These treatments were applied to mitigate pavement rutting (RUT) and roughness (IRI) in New Zealand. It was concluded that in-situ stabilization was more effective over the long term. Lu and Tolliver (2012) used performance jumps in IRI to calculate the effectiveness of hot mix overlay, crack sealing, aggregate seal, and chip seal treatments using data from the Long Term Pavement Performance (LTPP) program. In a study sponsored by the Louisiana Department of Transportation and Development (DOTD), Khattak and Baladi (2015) determined new 'reset values' for overlay, chip seal, micro surfacing, and replacement by plotting IRI of pavement sections against time and using best fit curves. Reset value is another description for pavement condition after treatment because of performance jump. In these examples, the performance jumps were calculated in terms of IRI and RUT instead of a composite index such as PCR.

CHAPTER 3 RESEARCH METHODOLOGY

This chapter includes the methodology of determining performance jumps for both asphalt and concrete pavements. In addition, approaches of developing the relationship between the calculated treatment benefit and Pre_PCR values, and evaluating performance curves following treatments are also presented.

3.1 Performance Jumps

This section describes the procedure to determine the performance jump, which can be calculated by subtracting the Pre_PCR value from the Post_PCR value after a specific treatment was performed. Several steps were involved in achieving this goal, as shown in Figure 2. These steps are the same for both asphalt and concrete pavements.

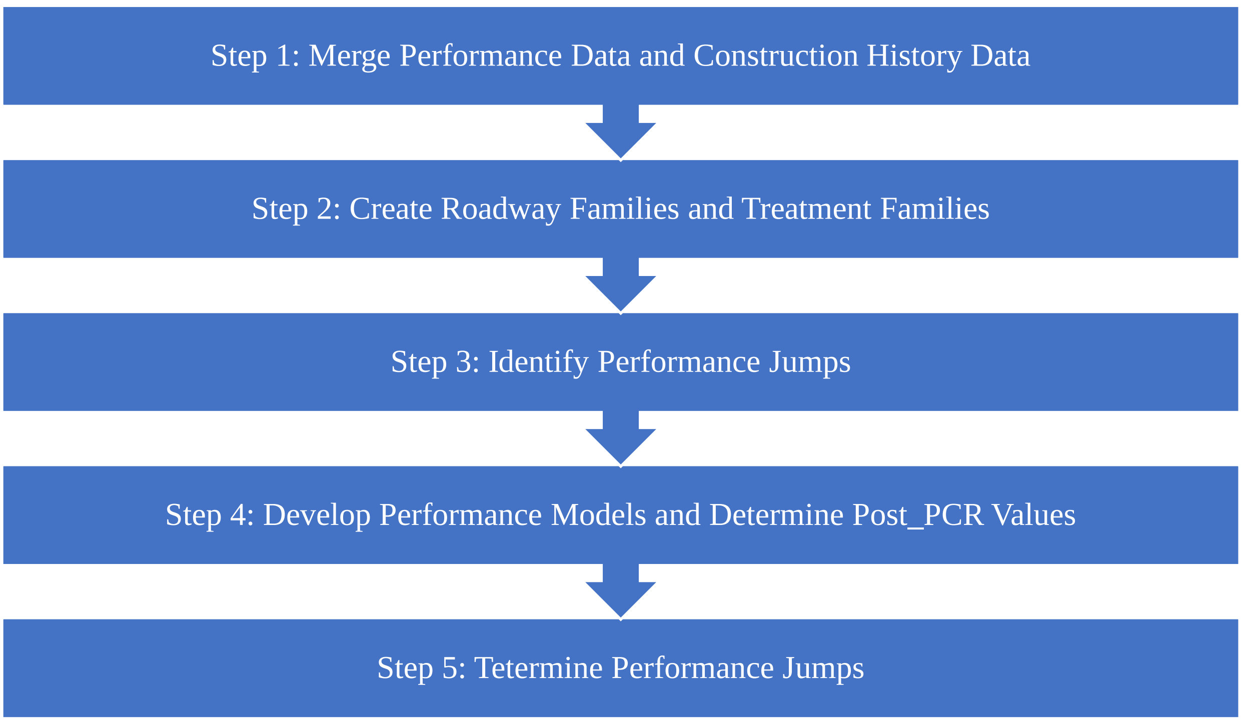

Figure 2: Methodology flowchart

3.1.2 Research Method

Detailed descriptions of the steps shown in Figure 2 are included in the following sections.

3.1.2.1 Step 1: Merge Performance Data and Construction History Data

The NCDOT records its pavement data in two separate datasets:

1. Windshield data for asphalt and concrete pavements
2. Statewide construction history

These two datasets were merged together, and the unified dataset was subdivided to obtain pavement and treatment families.

The windshield data includes the pavement distress information from the survey, along with the rating number (PCR) and Annual Average Daily Traffic (AADT) information. It also includes the year when the condition of the section was surveyed, termed as effective year (EFF_YEAR). The records available were from 1982 to 2010. This information was vital for creating pavement family datasets. On the other hand, the construction data has the year in which the section was constructed or reconstructed (completion year or YEAR_COMP), as well as the history of treatments applied on the roadway sections from 1920 to 2016. The treatment history was important to subdivide the pavement families into treatment families. The route and county information for the sections is common to both datasets.

For both asphalt and concrete pavements, the performance data was merged with the construction data, matching the route and county information to develop a unified dataset. A number of samples were then removed from the unified dataset whose year of construction was later than the year when it was surveyed. This condition was necessary to eliminate the possibility of negative age being reported, as age of a section is the difference between the year it was completed (YEAR_COMP) and the year it was surveyed (EFF_YEAR).

The construction history and performance data record the length of the sections differently. In the construction data, section length is recorded between mileposts (recorded as Begin_MP and To_MP) whereas the performance data records section lengths within offsets (OFFSET_FROM and OFFSET_TO). The length of the section surveyed is often times different than the length of the section that was treated (Chen and Mastin 2015). The merging process matches the sections based on their route and county information which leaves a possibility that the mileposts are either partially or entirely outside of the offset lengths.

The mileposts ending before the beginning of the offset, or beginning after the end of the offset, were removed entirely while the partially overlapping sections were evaluated based on the nine situations that occurred (Chen and Mastin 2015). The sections with at least 50% of the distance between their mileposts lying within the offsets were kept and the rest were discarded. A threshold of 50% was selected after conversation with the NCDOT engineers. The threshold captures a large number of sections, while avoiding sections whose overlap is too short as the after-treatment performance ratings of these short sections cannot accurately represent the performance of the remaining section that were not treated.

3.1.2.2 Step 2: Create Roadway Families and Treatment Families

Pavements in the unified dataset created were then grouped by functional classification and AADT, in order to develop roadway families. As shown in Table 1, a total of 14 asphalt (ASP) roadway families were developed in this study. In addition, one concrete (JCP) family was developed as well.

Table 1: Pavement Families

Functional Classification	AADT	Pavement Family
ASP Interstate	0-50k	Interstate 0-50k
	>50k	Interstate 50k+
ASP US	0-5k	US 0-5k

	5-15k	US 5-15k
	15-30k	US 15-30k
	>30k	US 30k+
ASP_NC	0-1k	NC 0-1k
	1-5k	NC 1-5k
	5-15k	NC 5-15k
	>15k	NC 15k+
ASP_SR (Secondary Routes)	0-1k	SR 0-1k
	1-5k	SR 1-5k
	5-15k	SR 5-15k
	>15k	SR 15k+

These roadway families were further sub-grouped into treatment families (e.g., SR 0-1k/Chip Seal). Prior to the creation of treatment families, the construction history was analyzed to extract the treatments recorded, which are presented in Table 2. These treatment types are common to both asphalt and concrete pavements, however not all of them are applied with the same frequency. Therefore, for this study, the treatments that had the greatest number of sections (Table 3 and Table 4) were considered for analysis.

Of these treatment types, the following adjustments were made:

- For ASP pavements:
  - The sections for 'Resurface', 'Resurface + Widen' and 'Resurface + Shoulder Work' were combined into 'Resurface' due to the similar nature of these two treatments. For the same reason, 'Mill + Resurface', 'Mill + Resurface + Shoulder' and 'Mill + Resurface + Widen' were also combined into 'Mill + Resurface'.
  - 'CRC Construction/Recon', 'JCP Construction/Recon', 'JCP Minor Rehab', and 'Unbonded Concrete Overlay (UBC)' were excluded because they are treatments for JCP pavements.
  - 'Shoulder Work' and 'Widen' were excluded because they are not included in the scope of work.
- For JCP pavements:
  - 'AC Construction/Recon', 'Chip Seal', 'Mill + Resurface /Mill + Resurface + Shoulder /Mill + Resurface + Widen', and 'Resurface /Resurface + Shoulder Work /Resurface + Widen' were excluded because they are treatments for ASP pavements.
  - 'CRC Construction/Recon', 'Shoulder Work' and 'Widen' were excluded because they are not included in the scope of work.

Table 2: Treatment types used by NCDOT

Treatment Type
AC Construction/Recon
Chip Seal
Crack Seal
CRC Construction/Recon
JCP Construction/Recon
JCP Minor Rehab
Mill + Resurface /Mill + Resurface + Shoulder /Mill + Resurface + Widen
Patching
Rehab
Resurface /Resurface + Shoulder Work /Resurface + Widen
Shoulder Work
Unbonded Concrete Overlay (UBC)
Widen

Table 3: ASP Treatments

Family	AC Construction/ Recon	Chip Seal	Mill+Resurfa..	Patching	Rehab	Resurface
Interstate 0-50k	849	26	2,468		52	3,262
Interstate 50kplus	34		93	4	12	266
US 0-5k	2,314	178	637	2		15,520
US 5-15k	4,989	103	2,419	3	6	21,274
US 15-30k	1,300	36	1,059	2		7,980
US 30kplus	190		249			1,994
NC 0-1k	1,397	569	140	1	5	11,913
NC 1-5k	2,129	771	1,272	1	1	45,897
NC 5-15k	1,469	216	1,308	2	14	20,212
NC 15kplus	747	29	579	1	8	3,802
SR 0-1k	10,866	127,692	313	34		194,546
SR 1-5k	438	7,603	765	9	1	70,406
SR 5-15k	262	516	824		8	19,452
SR 15kplus	83	55	230		2	3,891

Table 4: JCP Treatments

Crack Seal	JCP Con/Recon	JCP Minor Rehab	Patching	Rehab	Conc Overlay (UBC)
0	9,544	257	0	18	259

Table 3 shows the numbers of observations of the different treatment types in the pavement families for ASP pavements, while Table 4 shows the same information for JCP pavements. To ensure an adequate number of pavement sections for analysis, the following four treatment types were selected for analysis for ASP pavements:

1. AC Construction/Reconstruction
2. Chip Seal
3. Mill + Resurface
4. Resurface

The following three treatment types were selected for analysis for JCP pavements:

1. JCP Construction/Reconstruction
2. JCP Minor Rehab
3. Unbonded Concrete Overlay (UBC)

3.1.2.3 Step 3: Identify Performance Jumps

As described earlier, a performance jump occurs after a treatment is applied to a pavement section. It was imperative for this study to identify these sections and calculate their post_PCR values. The PCR values right before the sections identified with having a jump were flagged as Pre_PCR values. The Pre_PCR values were later used to calculate the performance jump as the difference between the pre and post-treatment PCR values.

The identification process involves finding the roadway sections where treatment was applied, flagging these observed jumps, and resetting their age using the 'Three-point Method' (Chen and Mastin 2015) so their influence can be appropriately considered during the development of performance models for treatment families. The resetting of age ensures that when a jump is identified, the age at which it occurred is set to be zero, and the ages of subsequent data points can be adjusted accordingly.

Table 5 shows the number of performance jumps in the ASP pavement families, while Table 6 shows the same information for JCP pavements.

Table 5: Number of ASP Performance Jumps

Family	AC Construction/ Recon	Chip Seal	Mill+Resurfa..	Patching	Rehab	Resurface
Interstate 0-50k	5		184		5	183
Interstate 50kplus	1		10			11
US 0-5k	46	23	78	1		1,012
US 5-15k	161	14	279	2	1	1,428
US 15-30k	42	2	106	1		599
US 30kplus	13		17			132
NC 0-1k	42	83	20	1		764
NC 1-5k	61	143	136			3,053
NC 5-15k	51	23	128			1,326
NC 15kplus	15	1	46			246
SR 0-1k	275	8,539	12	1		6,494
SR 1-5k	13	769	50		1	3,241
SR 5-15k	14	49	53		1	1,166
SR 15kplus	5	3	21			190

Table 6: Number of JCP Performance Jumps

Crack Seal	JCP Con/Recon	JCP Minor Rehab	Patching	Rehab	Conc Overlay (UBC)
0	843	41	0	0	31

3.1.2.4 Step 4: Develop Performance Models and Determine Post_PCR Values

Once the pavement sections with jumps were identified in the treatment families using the three-point method, their age and PCR values were used to predict the Post_PCR values. These Post_PCR values were calculated using the sigmoidal model equation at age zero. The sigmoidal model form was used because it fits the performance data well (Chen et al. 2014).

The expression for the sigmoidal model is:

$$y = \frac{a}{1 + e^{-\frac{x-b}{c}}}$$

Where:
y: PCR rating
x: pavement age
a, b, c: model parameters

In order to improve the accuracy of these estimates, the first 20 years of data was selected and the outliers were removed using a method based on Interquartile ranges, which is a standard outlier removal method (Shoemaker 2008). For the first 10 years, PCR values below the first quartile (Q1) were removed, whereas for the next 10 years PCR values above the third quartile (Q3) were removed. Additionally, all the data points at age zero were removed in order to estimate the Post_PCR value at age zero.

Table 7 shows the model parameters for ASP pavements while Table 8 shows the model parameters for JCP pavements. Once the final estimates of the model parameters were determined, these estimates were substituted into the equation and PCR for age zero was calculated. This new PCR value at age zero, designated as *P* in tables, is the Post_PCR for treatment families. The average Post_PCR values are also included in the tables. There are some empty cells in these two tables because some treatment families have very few or no observations. It should be noted that all three JCP treatment curves are not reasonable, very likely caused by the data quality issue. Therefore, it was decided that JCP pavements were excluded from further analyses. Figure 3 shows the model curve of Interstate 50k+ (AC Construction/Reconstruction). All other model curves are included in Appendix A.

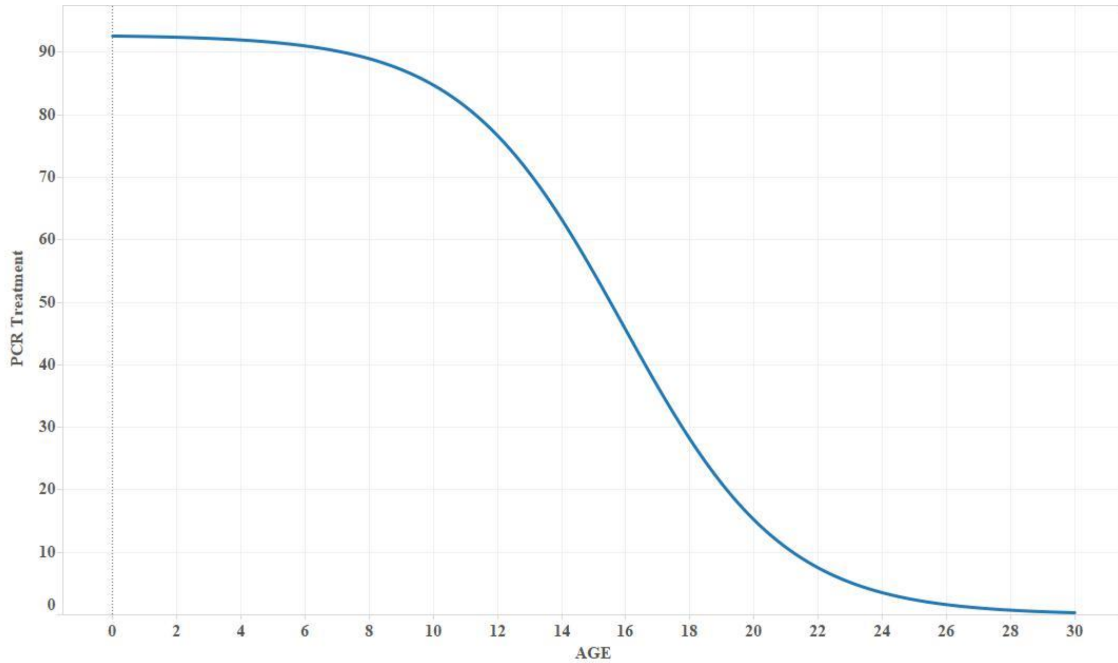

Figure 3: Interstate 0-50k (AC Construction/Reconstruction)

Table 7: Performance Model Parameters and Post-Treatment PCR Values for ASP Pavements

Family	AC Construction / Reconstruction				Chip Seal				Mill + Resurface				Resurface			
	a	b	c	P	a	b	c	P	a	b	c	P	a	b	c	P
Interstate_0_50k	97.51	13.17	-1.60	97.5					88.79	12.58	-1.84	88.7	92.97	13.37	-1.76	92.9
Interstate_50k+	92.76	15.91	-2.51	92.6					90.83	13.43	-1.91	90.7	95.13	13.61	-1.60	95.1
US_0_5k	93.56	13.29	-1.39	93.6	85.39	13.99	-3.05	84.5	89.10	12.19	-1.94	88.9	89.49	13.93	-2.79	90.5
US_5_15k	92.32	14.00	-1.99	92.2	83.03	13.61	-3.57	81.2	88.45	12.30	-1.94	88.3	89.03	13.63	-2.65	90.1
US_15_30k	90.84	13.81	-2.86	90.1	83.93	13.85	-2.14	83.8	85.67	13.81	-2.67	85.2	89.29	13.33	-2.36	89.0
US_30k+									87.09	14.29	-2.83	86.5	89.60	13.45	-2.41	89.3
NC_0_1k	86.66	14.19	-2.04	86.6	87.03	10.31	-2.84	84.8	88.90	12.29	-1.79	88.8	90.21	14.57	-2.49	90.0
NC_1_5k	91.47	13.99	-2.40	91.2	82.24	12.50	-2.43	81.8	89.24	11.48	-1.71	89.1	89.31	13.90	-2.53	88.9
NC_5_15k	93.33	14.07	-2.09	93.2	82.68	13.76	-2.99	81.9	84.65	12.14	-2.49	84.0	87.61	13.79	-2.66	87.1
NC_15k+	94.34	14.11	-2.29	94.1					89.13	11.61	-2.37	88.5	89.32	13.15	-2.65	88.7
SR_0_1k	93.09	13.87	-1.69	93.1	88.37	12.50	-2.38	87.9	87.53	12.21	-1.80	87.4	92.70	14.13	-2.15	92.6
SR_1_5k	87.91	13.96	-2.21	87.7	86.11	11.93	-2.65	85.2	90.16	14.15	-2.50	89.8	90.61	13.88	-2.32	90.4
SR_5_15k	97.32	12.36	-1.87	97.2	84.50	13.80	-3.33	83.2	86.06	13.39	-2.56	85.6	88.65	13.84	-2.66	88.2
SR_15k+	96.72	10.22	-1.43	96.6	92.71	9.33	-1.90	92.0	88.02	13.27	-2.54	87.6	88.23	13.28	-2.59	87.7
Mean				**92.8**				**84.6**				**87.8**				**90.0**

Table 8: Performance Model Parameters and Post-Treatment PCR Values for JCP Pavements

Family	JCP Construction / Reconstruction				JCP Minor Rehab				Unbonded Concrete Overlay (UBC)			
	a	b	c	P	a	b	c	P	a	b	c	P
JCP	100.00	20.00	-7.40	95.2	100.00	9.70	-2.24	100	97.34	255.80	-84.60	92.8

3.1.2.5 Step 5: Determine Performance Jumps

In this study, a performance jump is calculated by subtracting the Pre_PCR value from the Post_PCR value after a specific treatment was performed. The equation of calculating performance jumps is shown below:

$$\text{Performance Jump} = \text{Post\_PCR} - \text{Pre\_PCR}$$

Where:
Post_PCR: Post_Treatment PCR, estimated PCR values when age is zero. They are the *P* values in Table 7 and Table 8.
Pre_PCR: Pre_Treatment PCR, average PCR values observed right before pavements are treated.

Table 9 shows Pre_PCR values, Post_PCR values, and performance jumps for ASP pavements.

Table 9: Pre/Post_PCR Values and Performance Jumps for ASP Pavements

Family	AC Construction / Reconstruction			Chip Seal			Mill + Resurface			Resurface		
	Pre_PCR	Post_PCR	Jump	Pre_PCR	Post_PCR	Jump	Pre_PCR	Post_PCR	Jump	Pre_PCR	Post_PCR	Jump
Interstate 0-50k	71.6	97.5	25.9				66.1	90.4	24.3	66.2	93.9	27.8
Interstate 50k+	80.5	92.6	12.1				60.5	92.2	31.6	66.5	94.6	28.0
US 0-5k	62.7	93.6	30.9	46.0	84.5	38.6	56.0	89.4	33.4	61.1	90.5	29.4
US 5-15k	64.2	92.2	28.1	64.1	81.2	17.2	60.6	89.7	29.1	63.9	90.1	26.1
US 15-30k	63.0	90.1	27.1	52.1	83.8	31.7	62.4	86.8	24.4	64.2	90.4	26.1
US 30k+							70.7	87.7	17.0	64.1	90.7	26.6
NC 0-1k	57.5	86.6	29.1	58.8	84.8	25.9	48.3	89.3	41.0	60.9	91.7	30.8
NC 1-5k	56.7	91.2	34.5	55.3	81.8	26.4	57.3	89.7	32.4	63.2	90.6	27.4
NC 5-15k	55.6	93.2	37.6	57.2	81.9	24.7	55.1	85.6	30.5	60.9	88.8	27.8
NC 15k+	70.4	94.1	23.7				58.9	89.1	30.3	60.1	90.5	30.4
SR 0-1k	73.1	93.1	20.0	64.3	87.9	23.6	65.2	88.9	23.6	61.8	93.7	31.9
SR 1-5k	66.5	87.7	21.2	60.2	85.2	25.0	62.8	91.2	28.5	61.7	92.1	30.5
SR 5-15k	61.5	97.2	35.6	58.5	83.2	24.7	67.2	87.6	20.4	60.7	90.0	29.3
SR 15k+	49.4	96.6	47.2	69.4	92.0	22.6	64.3	88.8	24.5	64.6	89.2	24.7
Mean	**64.1**	**92.8**	**28.7**	**58.6**	**84.6**	**26.0**	**61.1**	**89.0**	**27.9**	**62.9**	**91.2**	**28.3**

Table 9 shows that for all 4 ASP treatment types, Interstate routes are not allowed to deteriorate too much and are treated at a higher threshold than other pavements. Figure 4 graphically illustrates the average pre/post_PCR values and performance jumps of 4 different ASP treatments. The results indicate that, on average, ASP pavements are being treated when the PCR is in the range of 58.6 to 62.9. Their Post_PCR values are between 84.6 and 92.8. Overall, *Asphalt Construction / Reconstruction* has the highest Pre_PCR, Post_PCR, and jump values, followed by *Mill + Resurface*, *Resurface*, and *Chip Seal*. These results are reasonable because *Chip Seal* treatments are usually less intensive which is evident from the fact the treatment shows the lowest average calculated jump and the lowest post_PCR value after treatment; *Asphalt Construction /*

Reconstruction shows the highest post_PCR value since it is a very intensive treatment and it would mitigate most of distresses in the pavements; *Mill + Resurface* and *Resurface* are moderate treatments which explains their Post_PCR values and jumps are between *Chip Seal* and *Asphalt Construction / Reconstruction.*

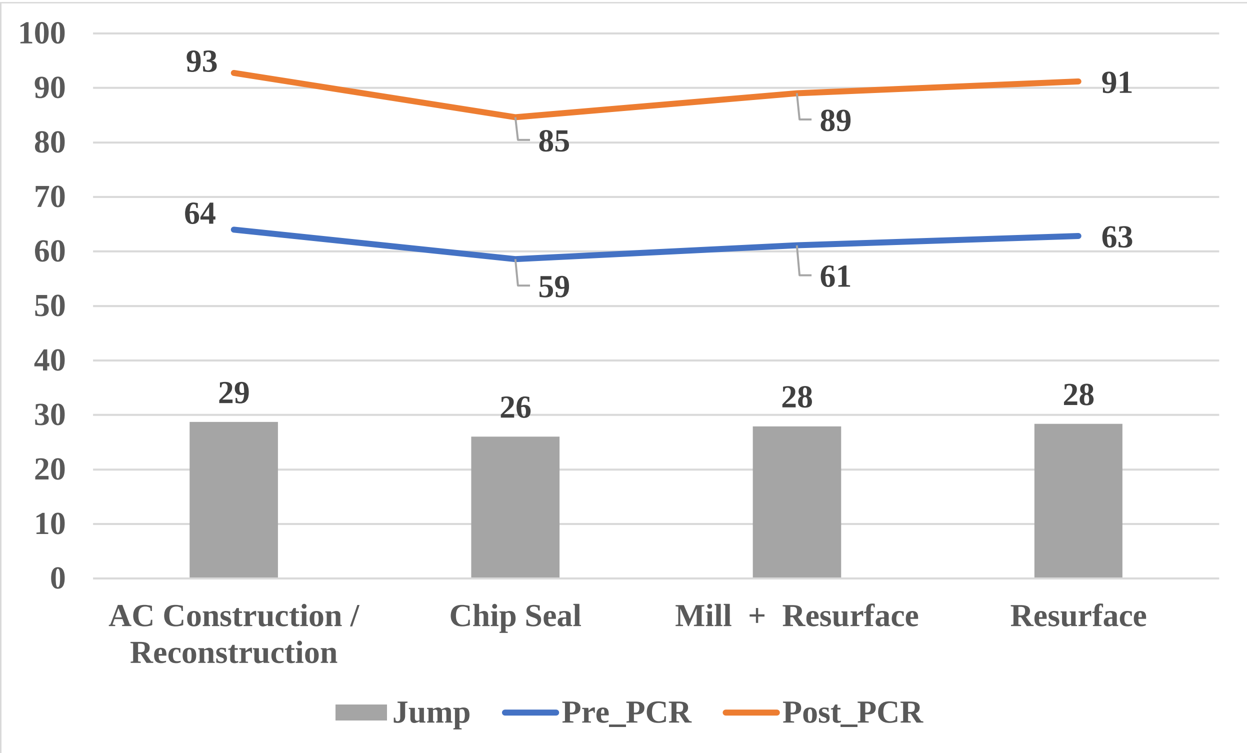

Figure 4: Average Pre/Post_PCR Values and Performance Jumps for ASP Pavements

3.2 Relationship Between the Calculated Benefit and Pavement Condition Ratings

The relationship between the PCR values, especially the Pre_PCR values, and calculated treatment benefits is essential because this relationship describes at what Pre_PCR value the largest treatment benefit can be achieved. In other words, this relationship can answer the question: when is the good timing to apply certain types of treatments?

3.2.2 Research Method

Several steps were involved in develop this relationship.

3.2.2.1 Step 1: Calculate Treatment Benefit

Treatment benefit is calculated through Cost-Benefit Analysis (CBA), which is a built-in function of the NCDOT PMS' software. To obtain more reasonable calculated benefit values, 33 possible sets of benefit weight factors were selected and used for CBA (Chen et al. 2014). Analysis constraints include: $713 million budget per year, all 14 NC divisions, and a 5-year analysis period. An excerpt of the final results is included in Appendix B.

3.2.2.2 Step 2: Merge Performance Data and Treatment Benefit Data

The goal of this step is to create a database that contains the Pre_PCR and calculated benefit for roadway sections that were selected for treatment (previous task). This requires the merging of two databases: performance data and treatment benefit data.

The following merging criteria were used:

- Route number must be the same;
- *From_MP = Offset_From*; and
- *To_MP = Offset_To*.

Sample sizes of ASP treatments of the merged data are included in Table 11. *AC Construction / Reconstruction* is the most expensive treatment type, and that might explain why only 11 roadways were selected for this treatment.

Several JCP pavement sections were selected during CBA, and all of them were treated by *JCP Minor Rehabilitation*. From the previous section, the *JCP Minor Rehabilitation* curve and its Pre_PCR values are not reasonable, therefore JCP sections were not included in further analyses.

Table 10: Merged Performance and Benefit Data: Sample Sizes

Treatment	Sample Size
AC Construction/Recon	11
Chip Seal	3,023
Mill+Resurface	325
Resurface	1,186

3.2.2.3 Step 3: Determine the Relationship of Pre_PCR and Treatment Benefit

Scatterplots of 4 ASP treatments (Treatment Benefit vs. Pre_PCR) are shown in Figure 5. Overall, *AC Construction / Reconstruction* has the largest benefit, followed by *Mill+Resurface* and *Resurface*, and *Chip Seal* has the smallest benefit. This order is the same as the one for performance jumps described previously, indicating that the more intensive a treatment is, then the higher the performance jump will be and the larger the treatment benefit obtained.

The average benefit of *AC Construction / Reconstruction*, *Chip Seal*, *Mill+Resurface*, and *Resurface* are 967.9, 490.9, 929.0, and 847.1, respectively.

To determine the best Pre_PCR values, a regression analysis using polynomial function was performance. Figure 6 shows the scatterplots with trend lines and confidence bands. The *AC Construction / Reconstruction* and the *Resurface* trend lines are not reasonable because they are concave up, indicating that the greatest benefit results from treatment of either a perfect pavement (PCR = 100) or a completely deteriorated pavement (PCR = 0). The causes are probably the very small sample size for *AC Construction / Reconstruction*, and the misclassification of treatment types for *Resurface*.

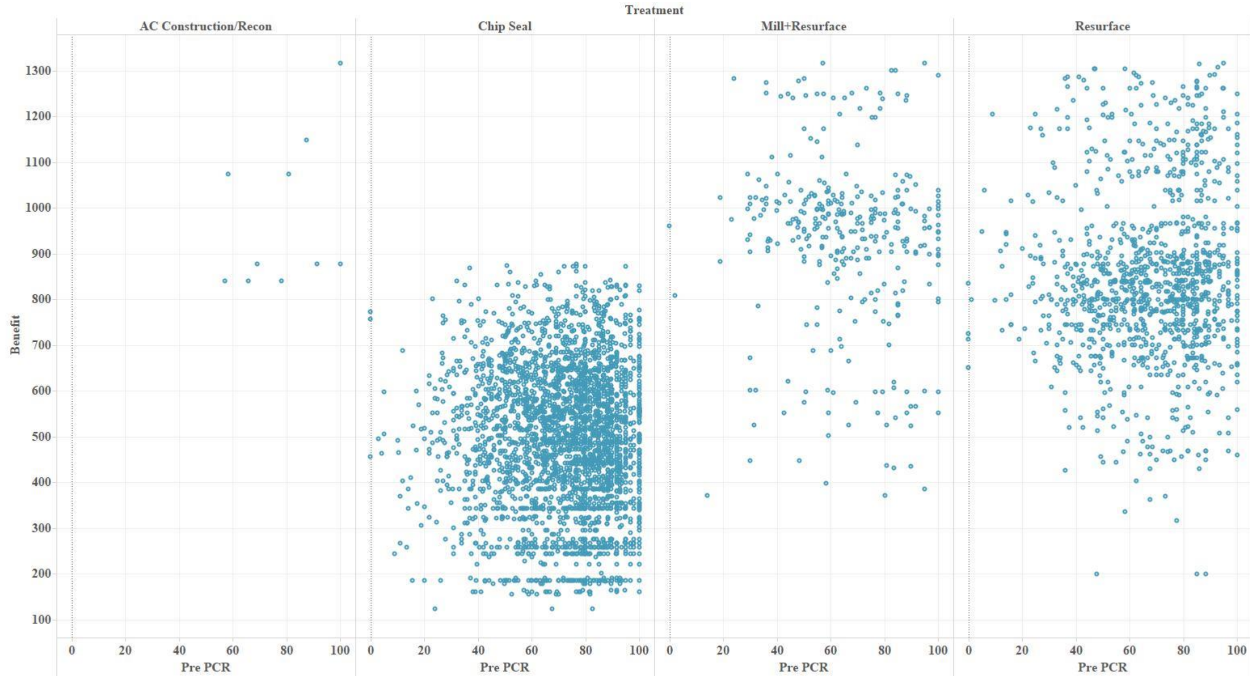

Figure 5: Scatterplots of Benefit vs. Pre_PCR

The remaining polynomial equations are:

For *Chip Seal*,

$$\text{Benefit} = 458.01525 + 1.59040 * \text{Pre\_PCR} - 0.01473 * \text{Pre\_PCR}^2 \quad (1)$$

For *Mill+Resurface*,

$$\text{Benefit} = 867.60629 + 3.26704 * \text{Pre\_PCR} - 0.03235 * \text{Pre\_PCR}^2 \quad (2)$$

The ideal Pre_PCR values can then be obtained by using the first derivative: for *Chip Seal*, the ideal Pre_PCR value is 53.98; for *Mill+Resurface*, the ideal Pre_PCR value is 50.49.

Currently in NCDOT's Needs Analysis, once a pavement section's PCR value reaches 60, it is eligible to be treated. According to the two ideal Pre_PCR values obtained in this study, it seems that if *Mill+Resurface* or *Chip Seal* has been selected, NC pavements can be treated one year later and still have a slight benefit gain. It should be noted, however, that roadways that are not treated on time can cause safety issues, affect public perception and the overall network performance. Therefore, it is essential that engineers need to carefully evaluate pros and cons associated with each option before making the final maintenance decision.

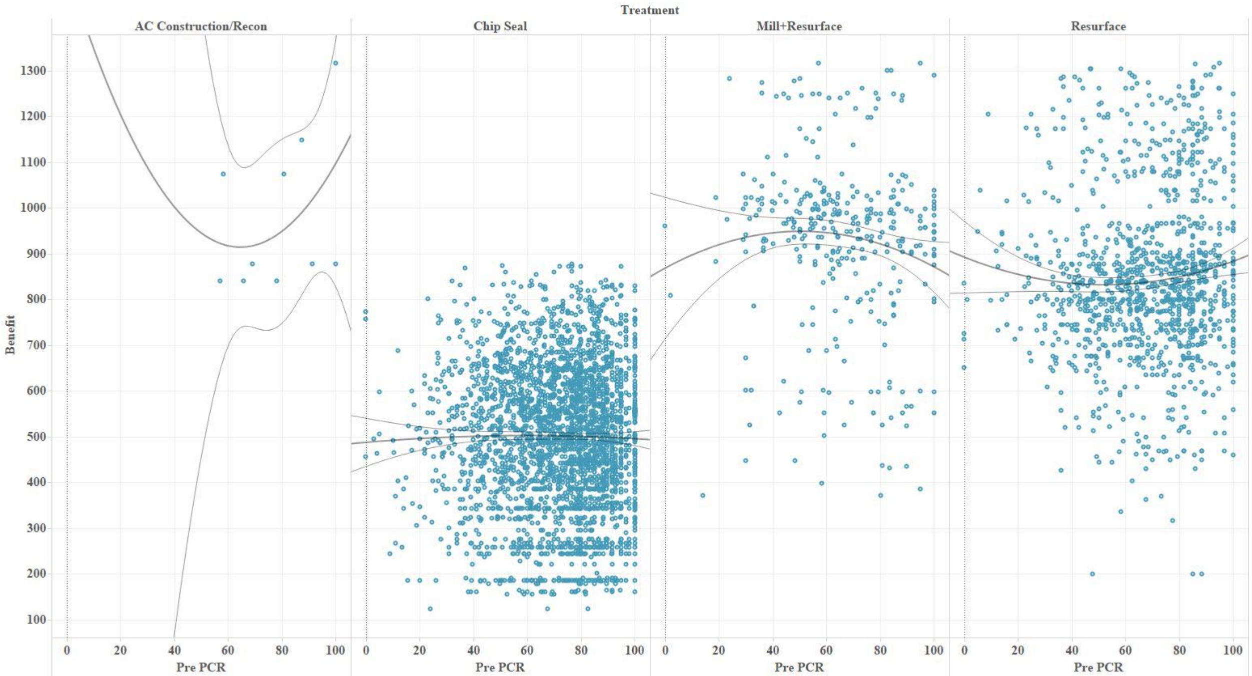

Figure 6: Scatterplots of Benefit vs. Pre_PCR with Trend Lines

3.3 Evaluate Performance Curves Following Treatments

This section is to present a visual comparison between treatment curves and original performance curves developed in a previous study (Chen et al. 2014), to determine if these groups of two curves are parallel, rejoining, or have some other form. Figure 7 shows an example, which is a comparison of Interstate 50k+: *AC Construction / Reconstruction* vs. Original. Other comparison figures are included in Appendix C.

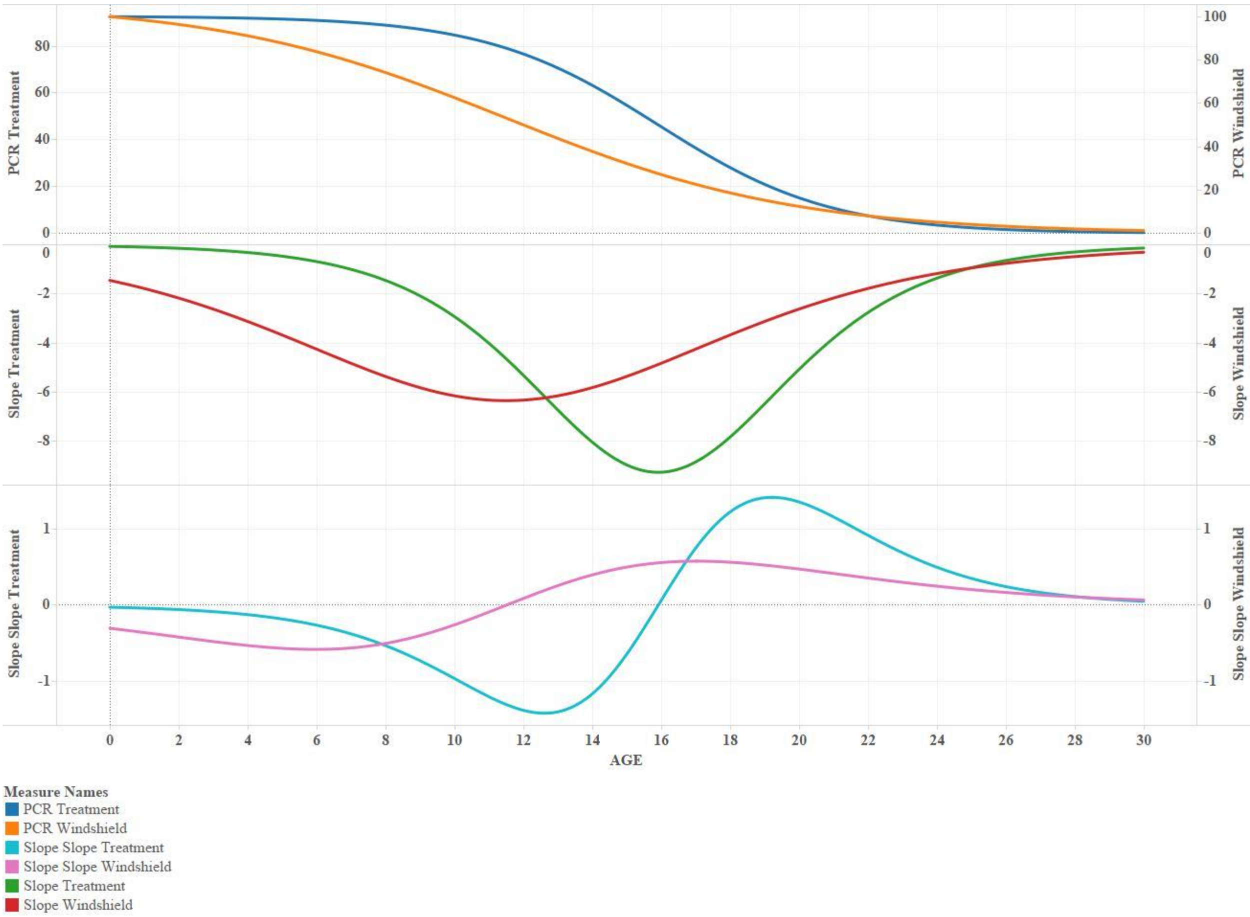

Figure 7: *Interstate 50k+: AC Construction / Reconstruction* vs. Original

Figure 7 has three panels. The common x-axis for all three panels is Pavement Age.

The top panel includes two performance curves, and its y-axis is PCR. The "PCR Treatment" curve represents the *AC Construction / Reconstruction* curve (post-treatment curve); while the "PCR Windshield" curve represents the original performance curve. It should be noted that the scales of y-axis are different. This allows two curves with different intercepts to start from the same point, making visual comparison easier. In this case, the two curves have the same slope at around Age 12.3 (when two curves meet in the middle panel) and eventually rejoin.

The middle panel includes two slope curves. The "Slope Treatment" curve represents slopes (first derivatives) of the *AC Construction / Reconstruction* curve; while the "Slope Windshield" curve represents the same information for the original performance curve. The treatment curve and the original performance curve are parallel when the two curves in this panel are equal. In this case, all slopes are negative indicating the two functions in the top panel are decreasing over Age.

The bottom panel includes two slope of slope curves. The “Slope Slope Treatment” curve represents slopes (second derivatives) of the slope curve in the middle panel; while the “Slope Slope Windshield” curve represents the same information for the original performance curve. In this case, the “Slope Slope Treatment” curve has a larger change than the “Slope Slope Windshield” curve between Age 12 and 18, indicating that the treatment curve has a greater change (drop) in PCR than the original performance curve between Age 12 and 18.

From 51 ASP comparison figures (Appendix C), except for *Chip Seal*, it is obvious that the two curves are following the same trend as seen in Figure 7: parallel and rejoin. For *Chip Seal*, the treatment curve quickly rejoins the original curve and then stays below it. This means that *Chip Seal* curve quickly under-performs the original curve.

CHAPTER 4 FINDINGS AND CONCLUSIONS

In this study, effort has been made to determine pavement performance jumps after treatment, which are defined as the difference between pre-treatment and post-treatment Pavement Condition Rating (PCR) values. Consequently, the study has analyzed the pavement performance data collected by windshield surveys, divided it into treatment families which were based on the most common treatments applied by the NCDOT on their asphalt and concrete pavements, calculated Pre-treatment and post-treatment PCR values to determine the performance jumps, and developed after-treatment performance curves. These jumps along with the performance curves can provide better prediction of the pavement condition over its life after a treatment is applied and assist NCDOT engineers in developing effective treatment plans.

Based on the study of 56 roadway treatment families, the following conclusions have been drawn:

- In North Carolina, *AC Construction/Reconstruction, Chip Seal, Mill + Resurface*, and *Resurface* are the most commonly applied treatments for ASP pavements; and *JCP Construction / Reconstruction, JCP Minor Rehabilitation*, and *Unbonded Concrete Overlay (UBC)* for JCP pavements.

- Post-treatment ASP performance curves' intercepts are not 100. In descending order, their average values are 92.8, 90.0, 87.8, and 84.6 for *AC Construction/Reconstruction, Resurface, Mill + Resurface*, and *Chip Seal*, respectively. This means that an *AC Construction/Reconstruction* treatment can typically bring a roadway section's PCR value back to 92.8, while a PCR value of 84.6 if *Chip Seal*, a less intensive treatment, is applied instead. The intercept of *Mill + Resurface* should be higher than *Resurface* because it is a more intensive treatment; this needs to be further studied.

- In descending order, average performance jumps of ASP treatments are 28.7, 28.3, 27.9, and 26.0 for *AC Construction/Reconstruction, Resurface, Mill + Resurface*, and *Chip Seal*, respectively. This means that an *AC Construction/Reconstruction* treatment can typically improve a roadway section's PCR value by 28.7, and so forth. Similar to the previous finding, the order of *Resurface* and *Mill + Resurface* should be reversed, which needs a further study.

- Results of Cost-Benefit Analysis (CBA) indicate that among 4 ASP treatments, *AC Construction / Reconstruction* has the largest benefit, followed by *Mill+Resurface* and *Resurface*, and *Chip Seal* has the smallest benefit. This order is the same as the one for performance jumps described previously, meaning that the more intensive a treatment is, then the higher the performance jump will be and the larger the treatment benefit obtained.

- To obtain the highest treatment benefit, the best timing to applying ASP treatments are: for *Chip Seal*, when Pre_PCR value is 53.98; for *Mill+Resurface*, when the Pre_PCR value is 50.49. Currently in NCDOT's Needs Analysis, once a pavement section's PCR value reaches 60, it is eligible to be treated. Based on the findings on the best timing, it seems that if *Mill+Resurface* or *Chip Seal* has been selected, deferring treating NC pavements by one year might ease budget constraints and still have a slight benefit gain. It should be noted, however, that roadways that are not treated on time can cause safety issues, affect public perception and the overall network performance. Therefore, it is essential that engineers need to carefully evaluate pros and cons associated with each option before making the final maintenance decision.

- Except for *Chip Seal*, all other ASP treatment curves follow the same deterioration trend: parallel and then rejoin the original performance curves. For *Chip Seal*, the treatment curve quickly rejoins the original curve and then stays below it. This means that *Chip Seal* curve quickly under-performs the original curve.

CHAPTER 5 RECOMMENDATIONS

Based on the findings of this study, recommendations for avenues of further research are highlighted below:

- It is recommended to combine *Mill + Resurface* and *Resurface* data and study their performance in a future study. *Mill + Resurface* is a more intensive treatment than *Resurface*, its performance, according to the results of this study, however, was worse than *Resurface*. It is possible that the decision of using *Mill + Resurface* was made not based on distress severities, but for maintaining geometric and operational features of curb and gutter. Therefore, data of these two treatments probably should be combined and studied again.

- It is recommended to use the average Pre_PCR values determined in this study to define pretreatment conditions for future performance models. Pretreatment condition can significantly impact pavement performance. One way to include pretreatment condition in the performance evaluation process is to include it as a grouping factor when develop performance models. For example, the US 0-5k family can be divided into two sub-families based on Good/Poor pretreatment condition: US 0-5k /Good and US 0-5k /Poor, and these family models can be developed to more accurately predict pavement performance. In this process, the average Pre_PCR values determined in this study can be used as thresholds to define Good and Poor conditions.

- It is recommended that the influence of other factors associated with treatments be considered. This study focused on the dominant types of treatments applied, and future studies may focus on the materials used in these treatments, the thicknesses of overlays, and the effects of combinations of potential factors.

CHAPTER 6 IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The outcomes of this study will be disseminated through the following venues:

- Providing project deliverables. Project deliverables, in both hard copy and digital format, as described in the "Anticipated Research Products" section of this proposal, will be provided to NCDOT.

- Generating research publications. Research findings will be published in peer reviewed journals, such as Transportation Research Record (TRR) and ASCE journals.

- Presenting at national/international professional conferences, for example, TRB annual conference and ASCE conferences.

- Transferring the technology to NCDOT. Short course or demonstrations can be provided to NCDOT personnel regarding approaches of developing models, deriving trigger points, and calculating weight factors.

- Integrating research findings into engineering courses at UNC Charlotte. In the past three years, the PI has integrated the methodologies and findings of previous NCDOT studies into a senior level undergraduate course entitled "Highway Design and Construction". This integration resulted in increased interest in working in the transportation industry, and increased participation in transportation related research among undergraduate students. The PI will continue this holistic approach in this study.

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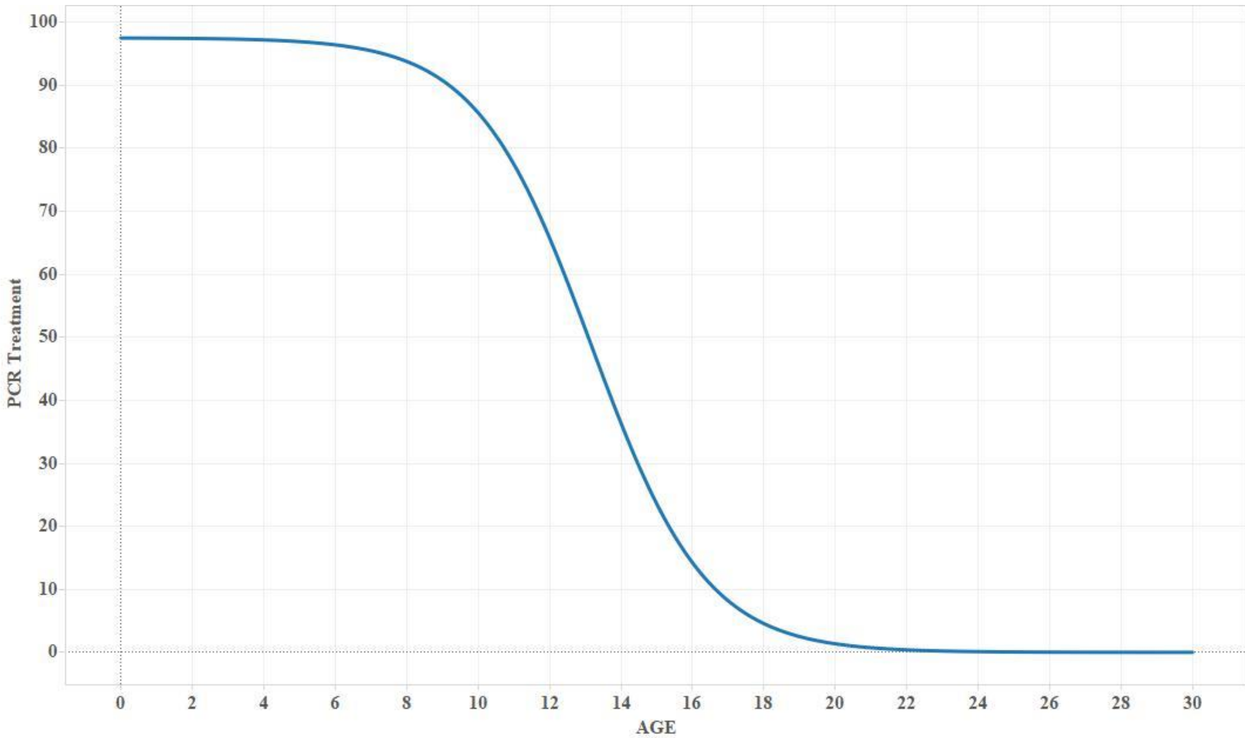
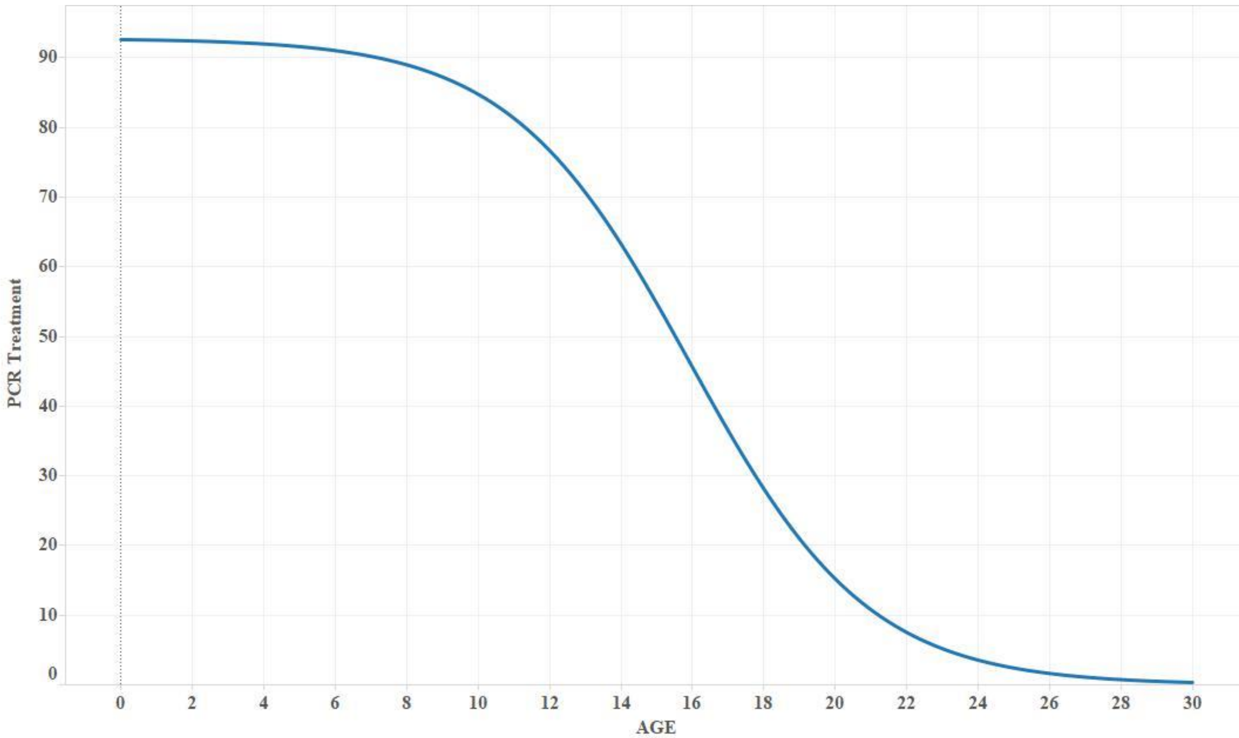
Appendix A – Post Treatment Performance Model Curves



Interstate 0-50k (AC Construction/Reconstruction)



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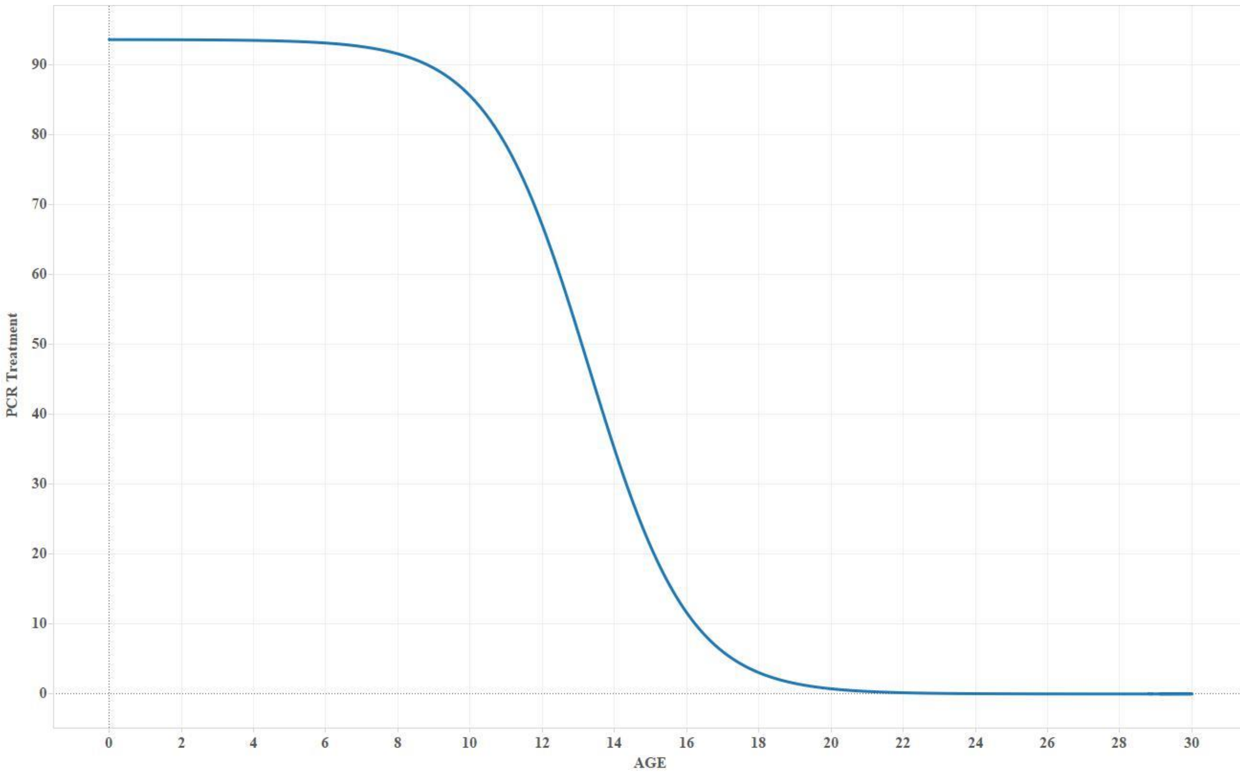

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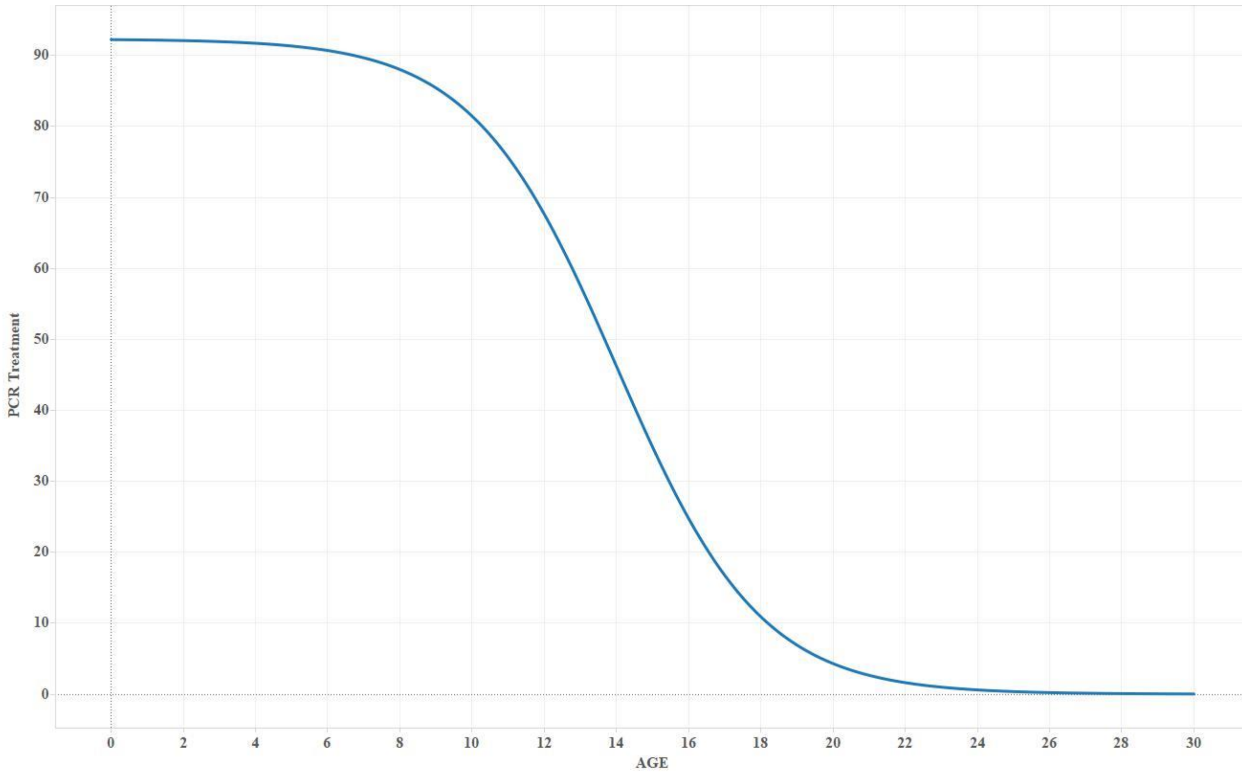

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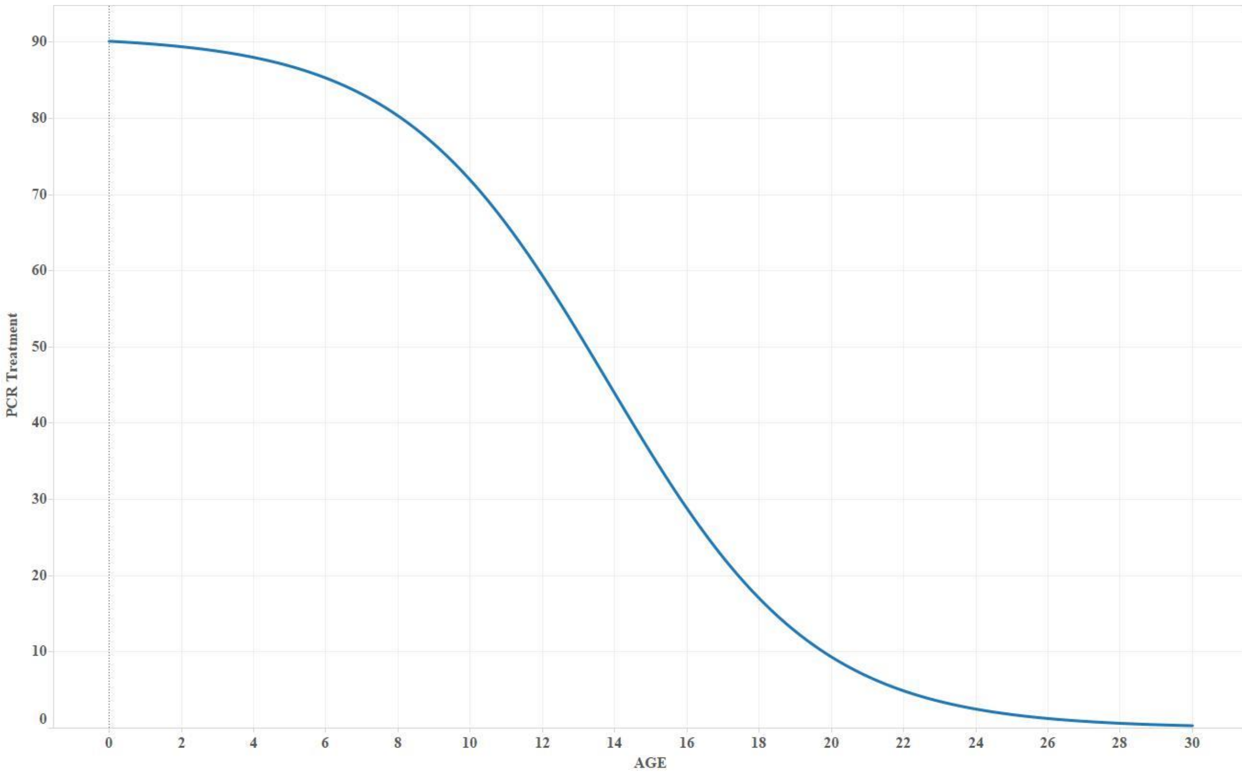

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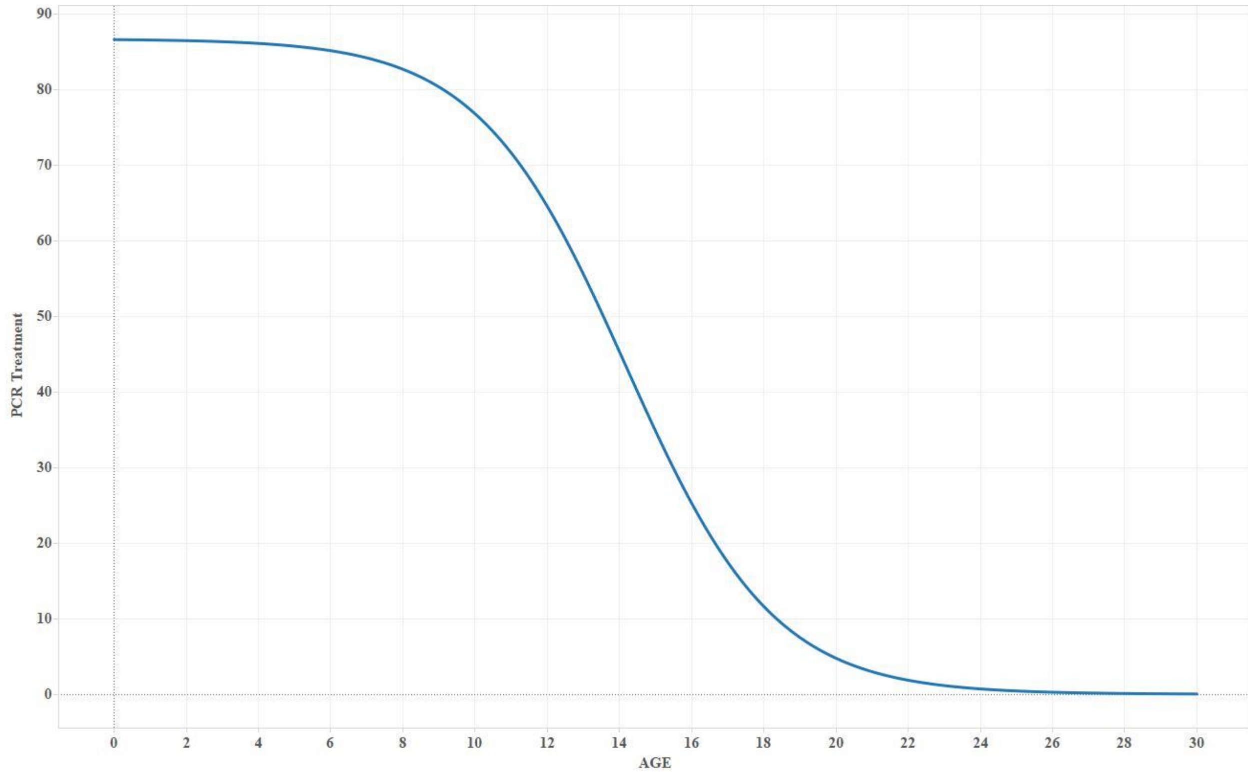

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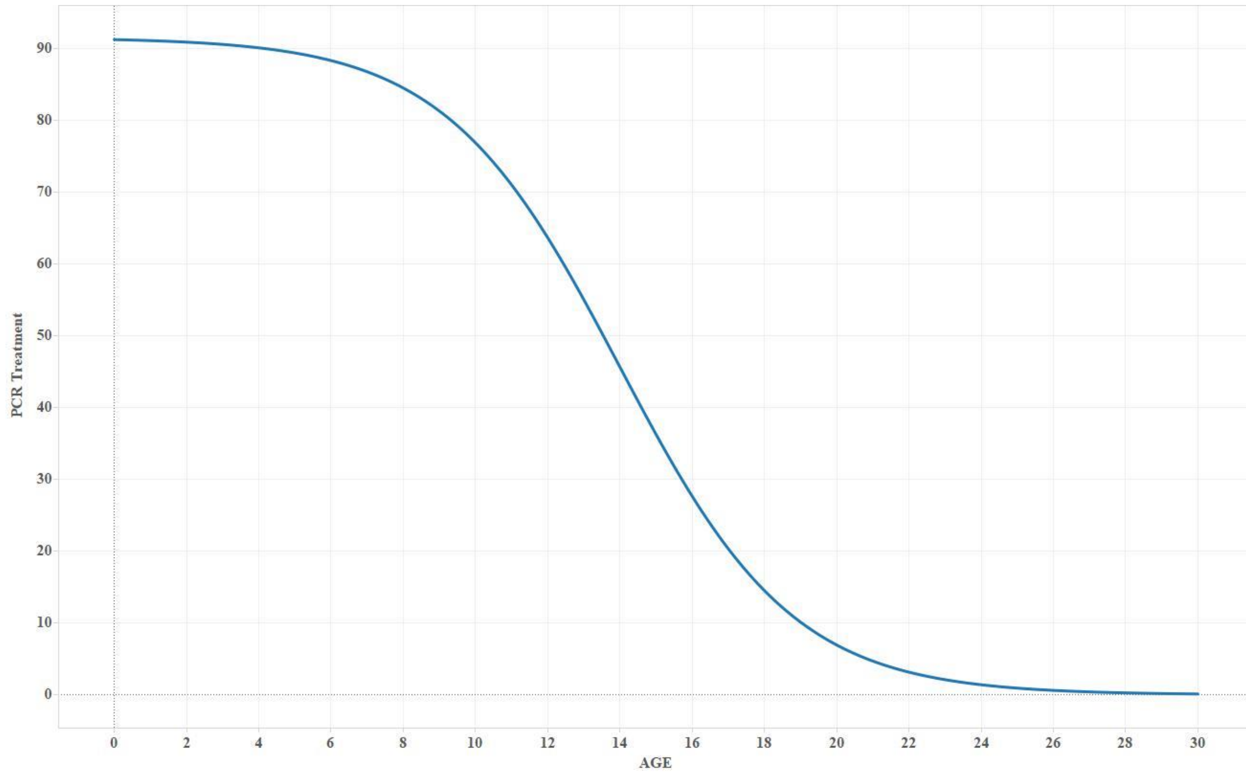

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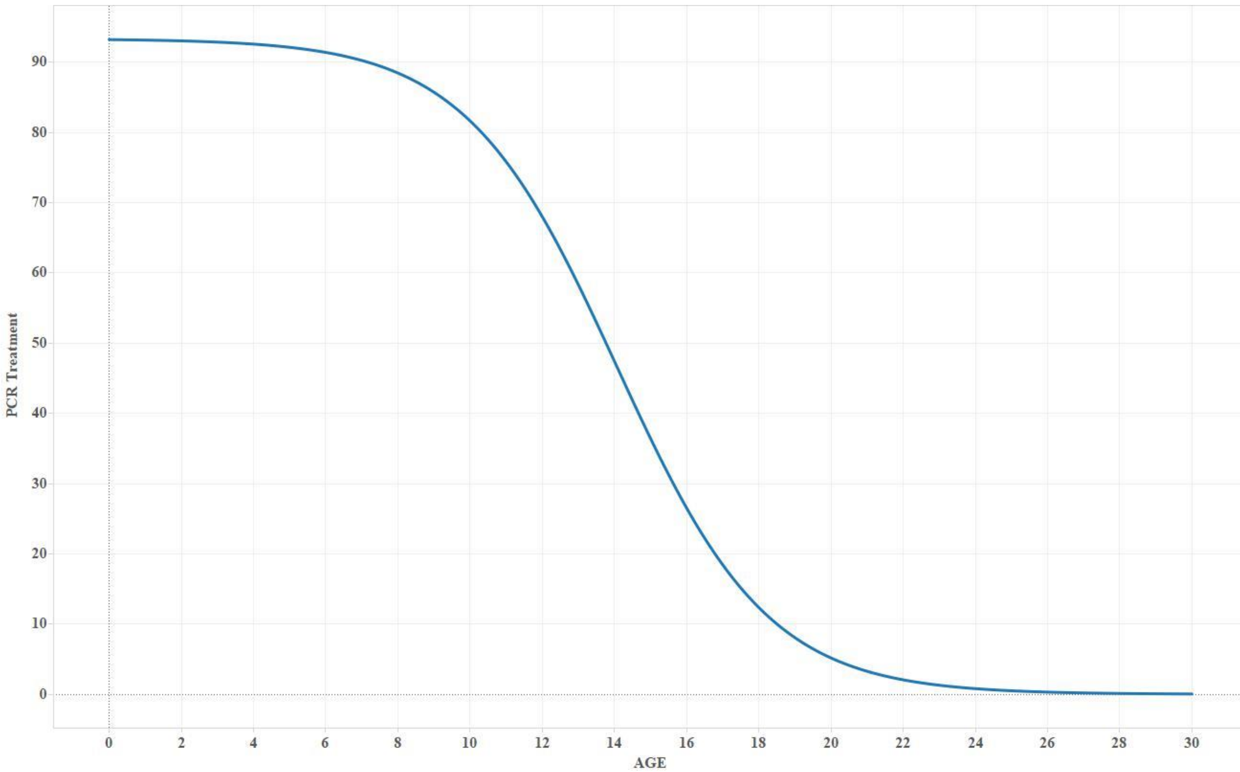

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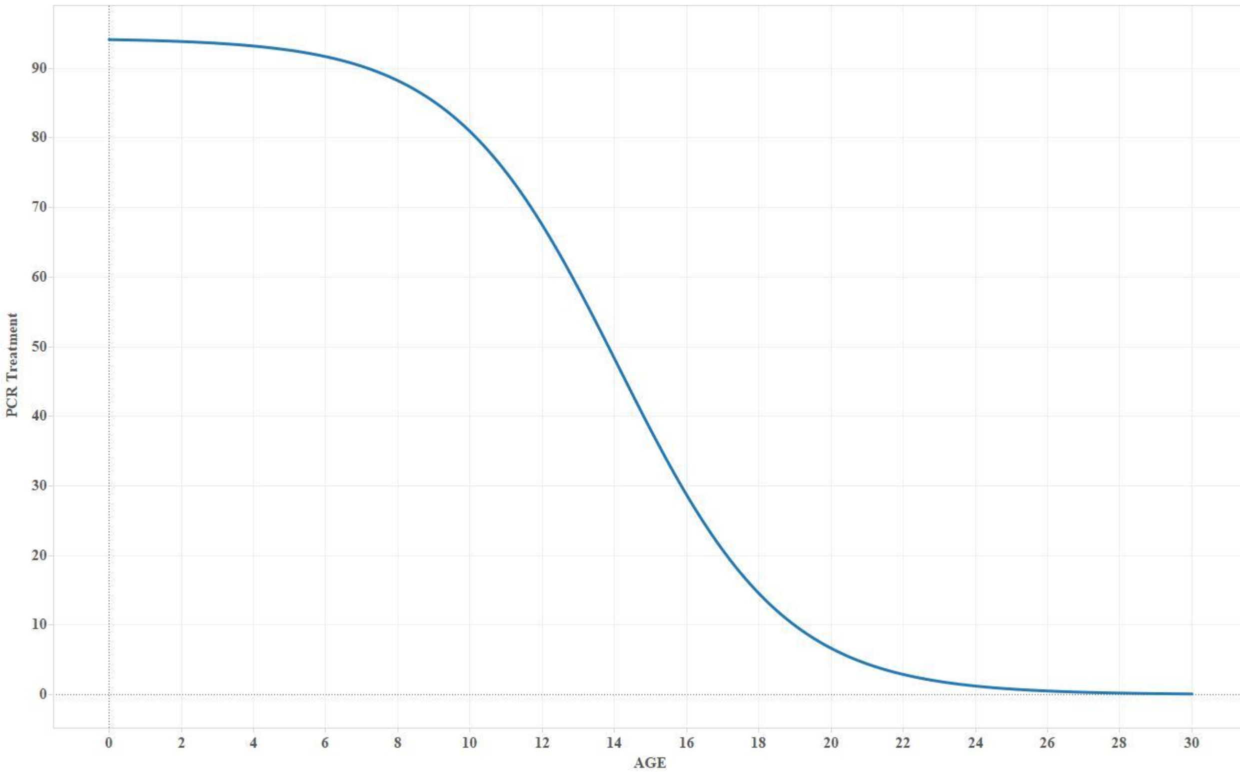

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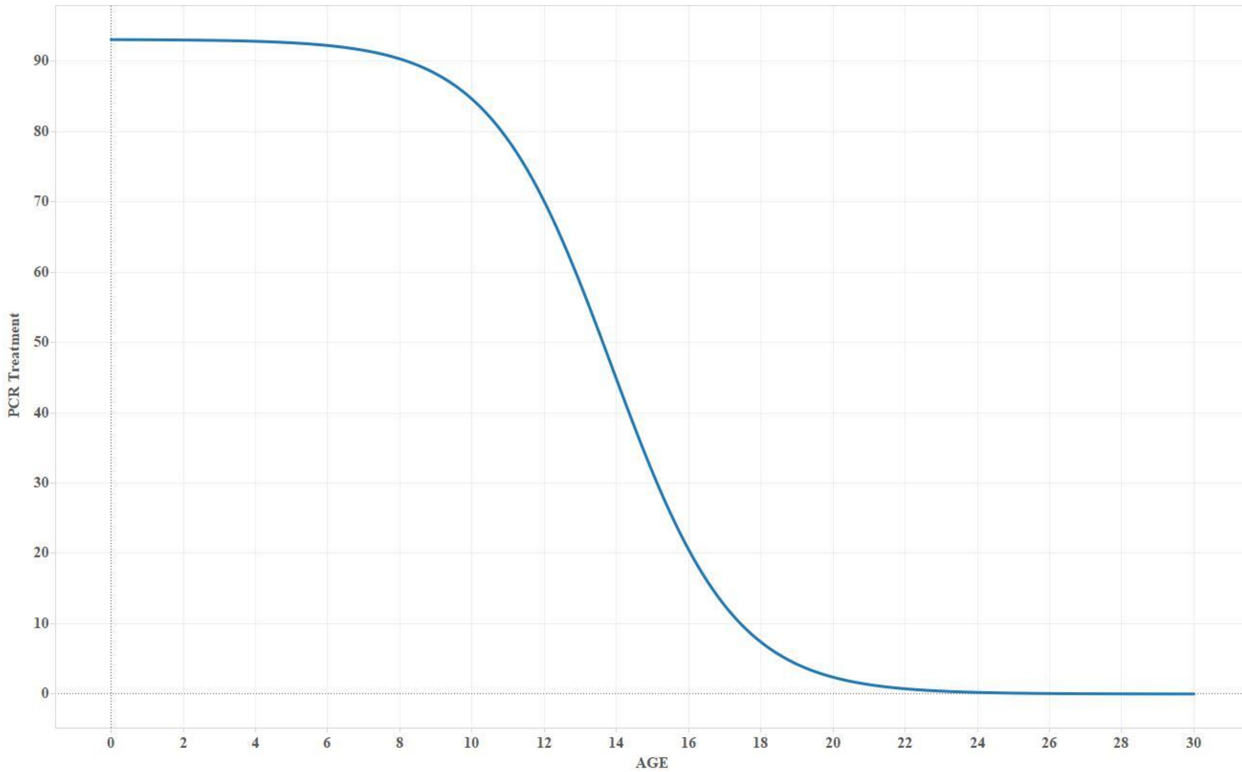

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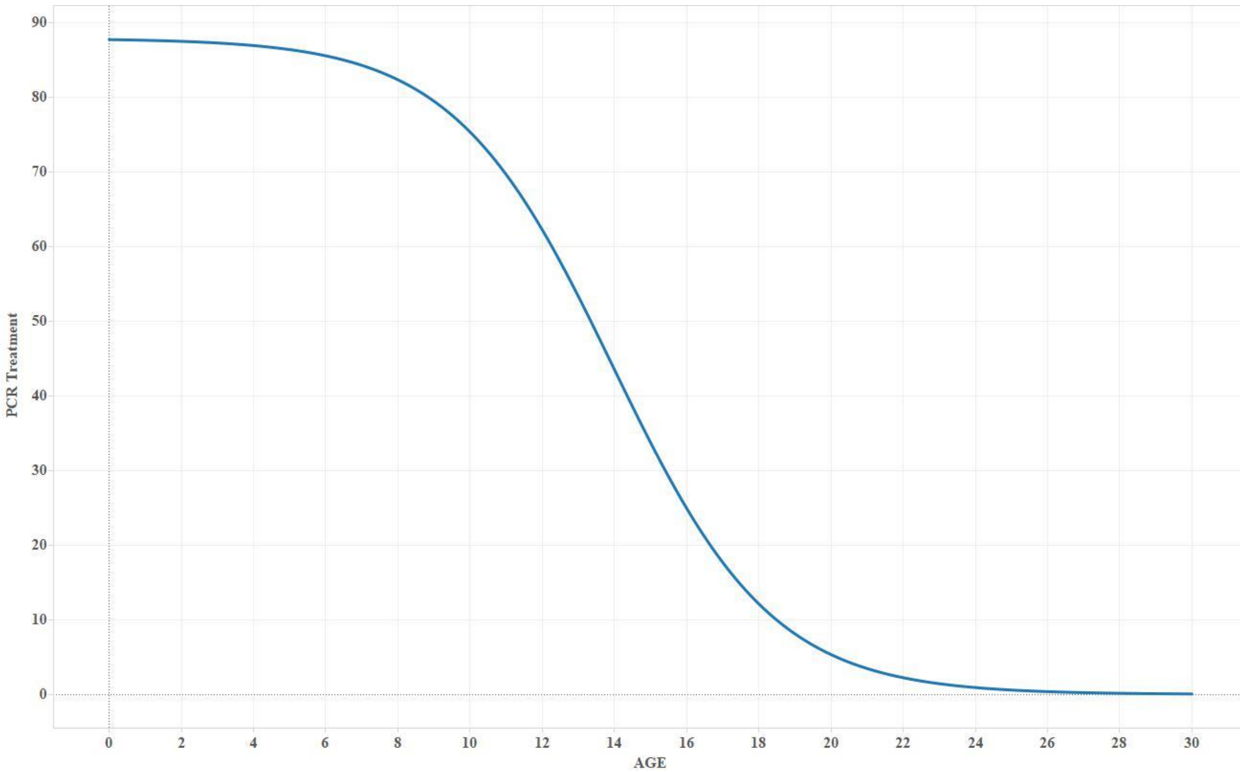

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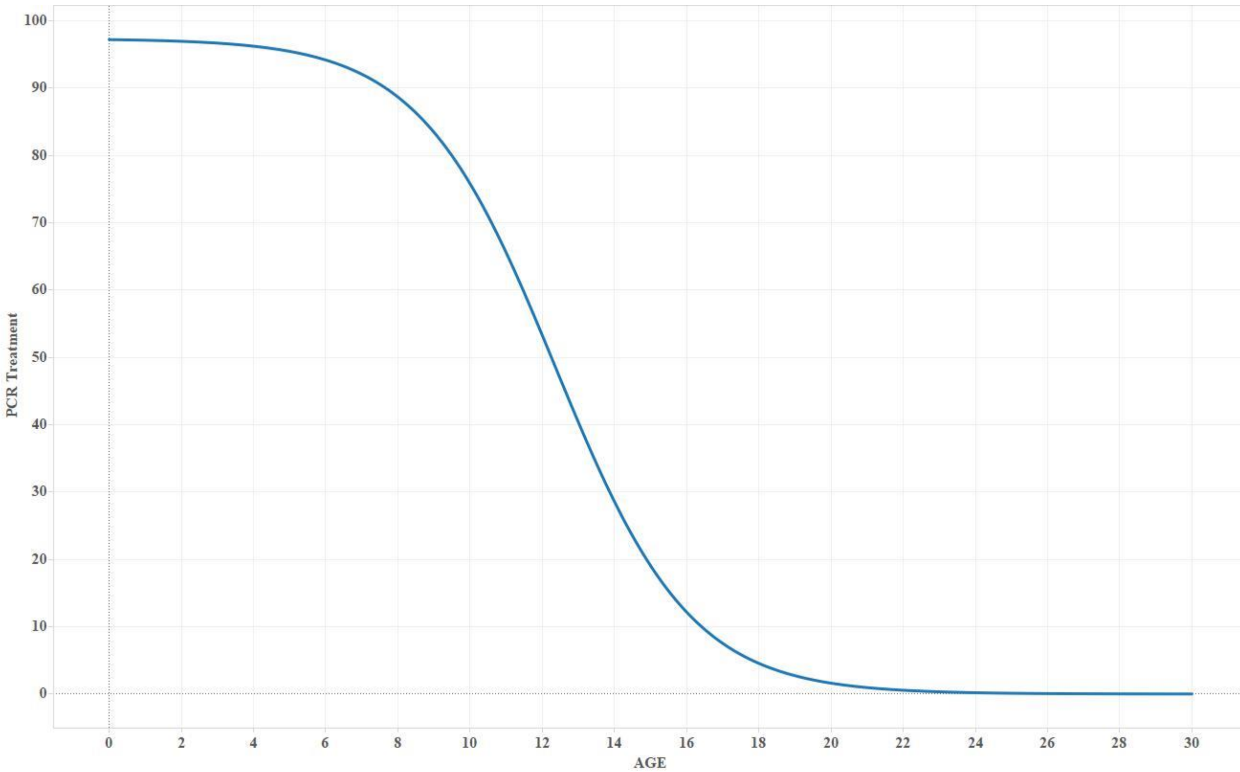

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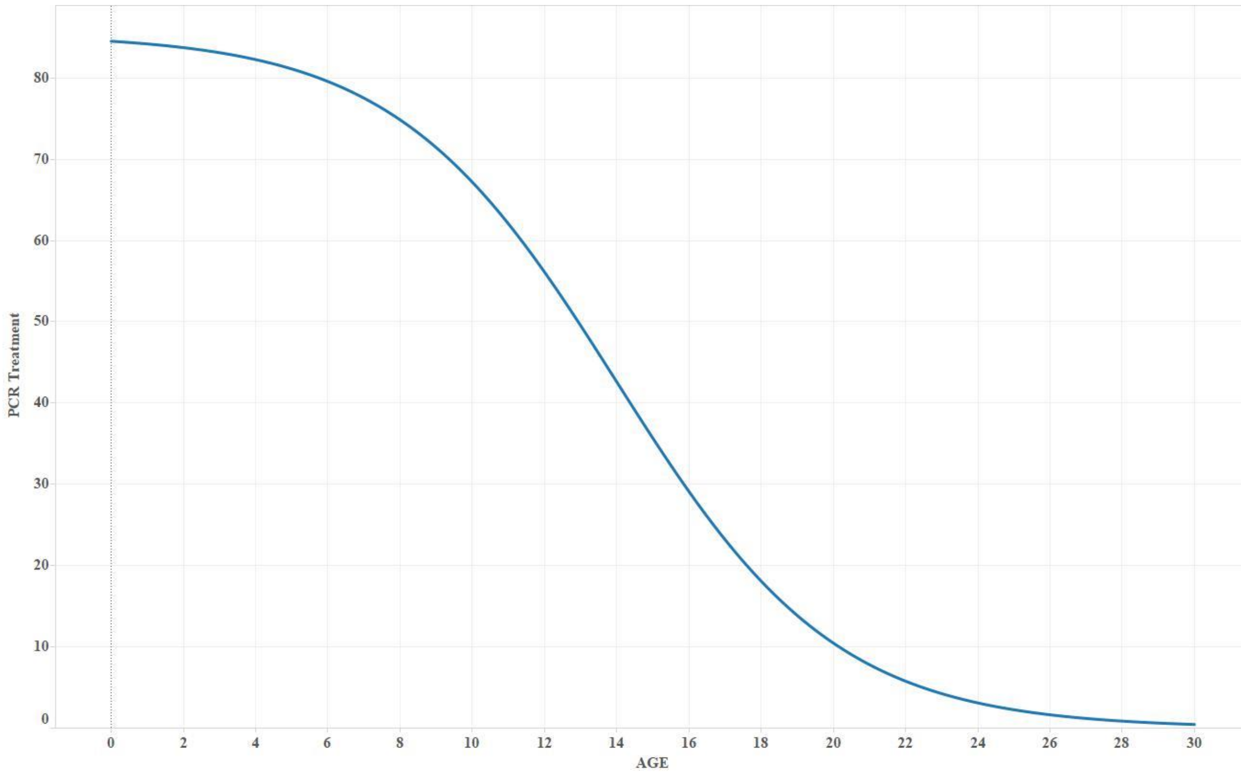
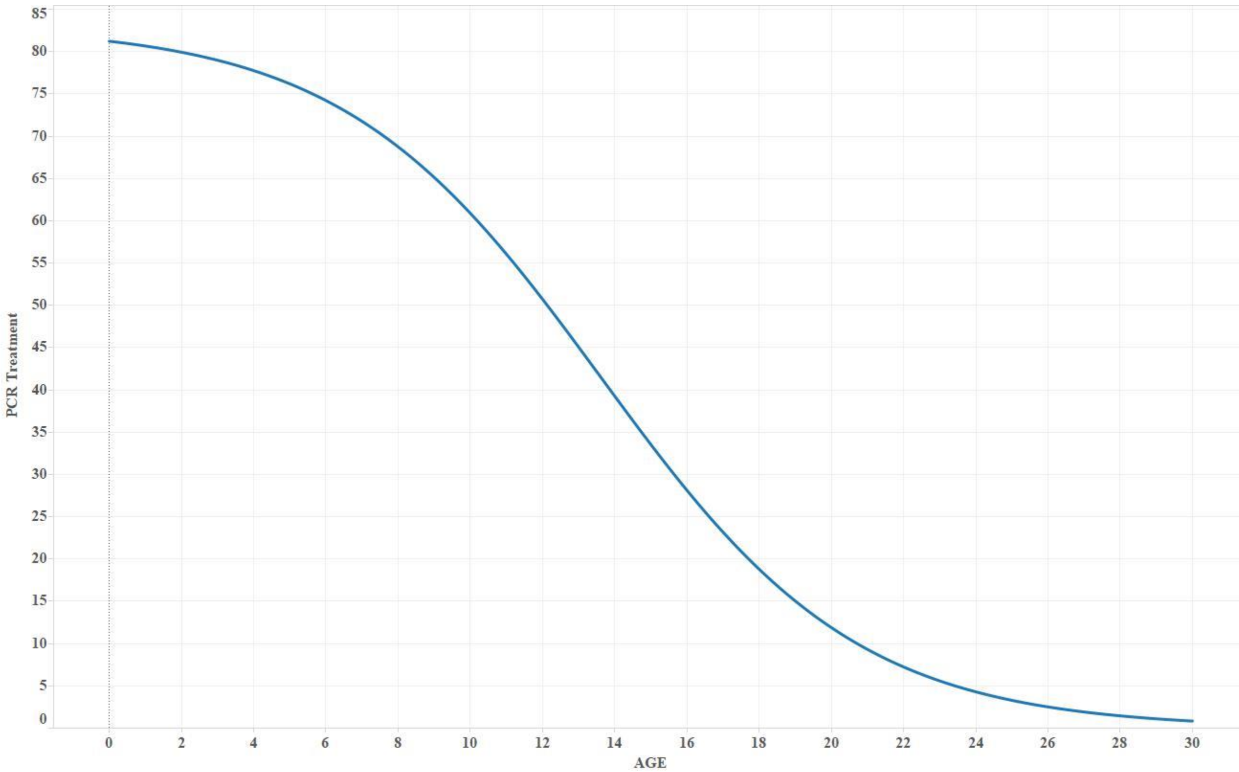


US 0-5k (Chip Seal)



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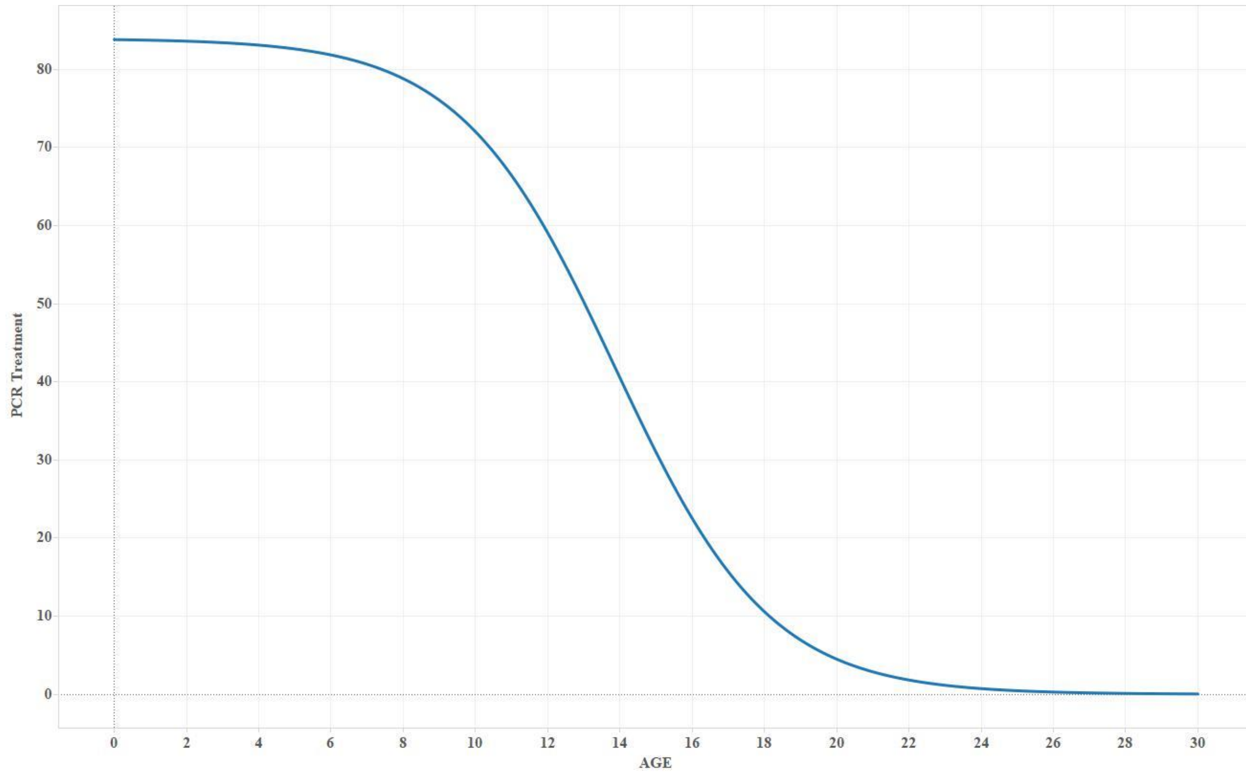

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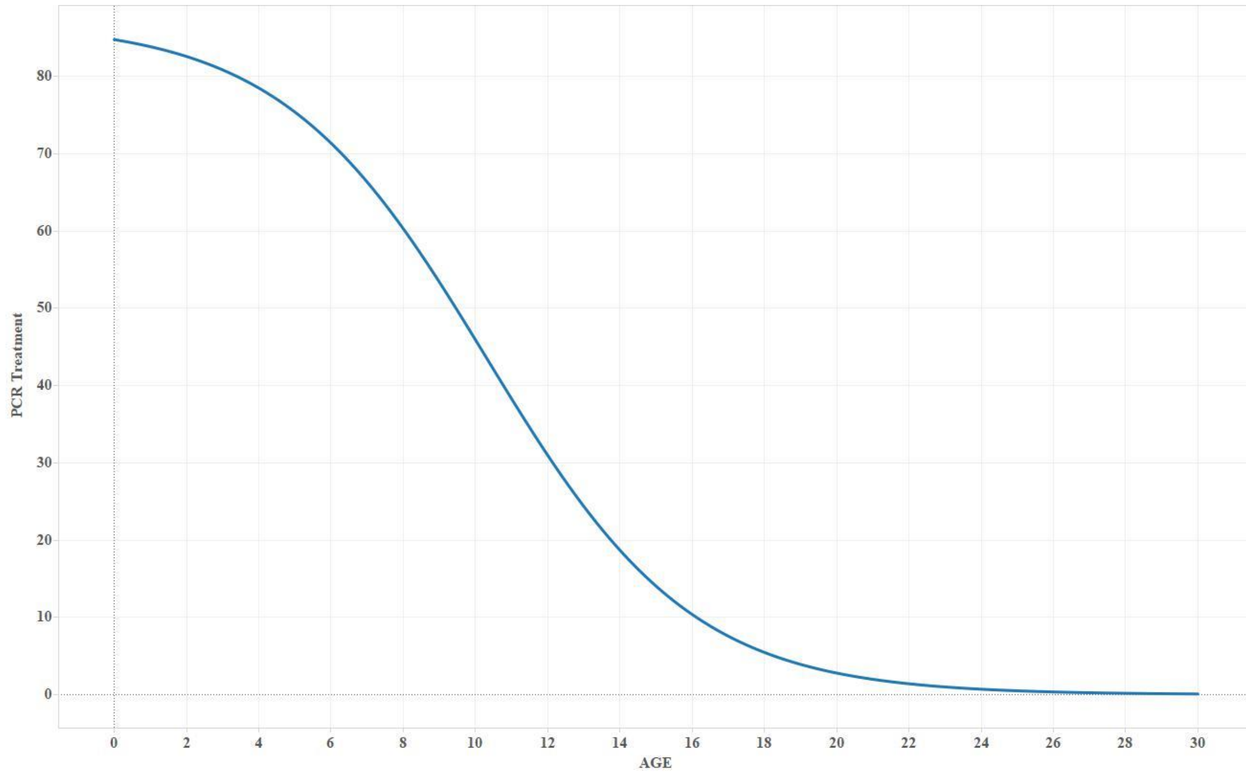

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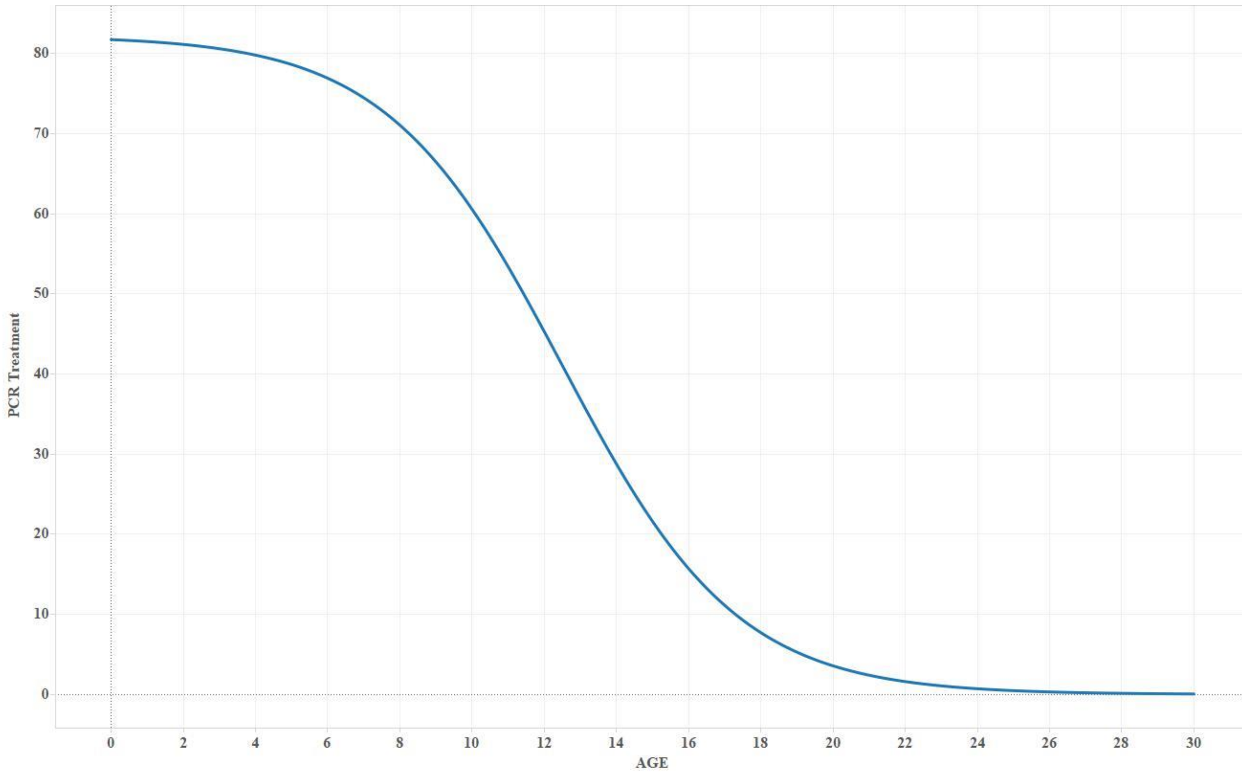

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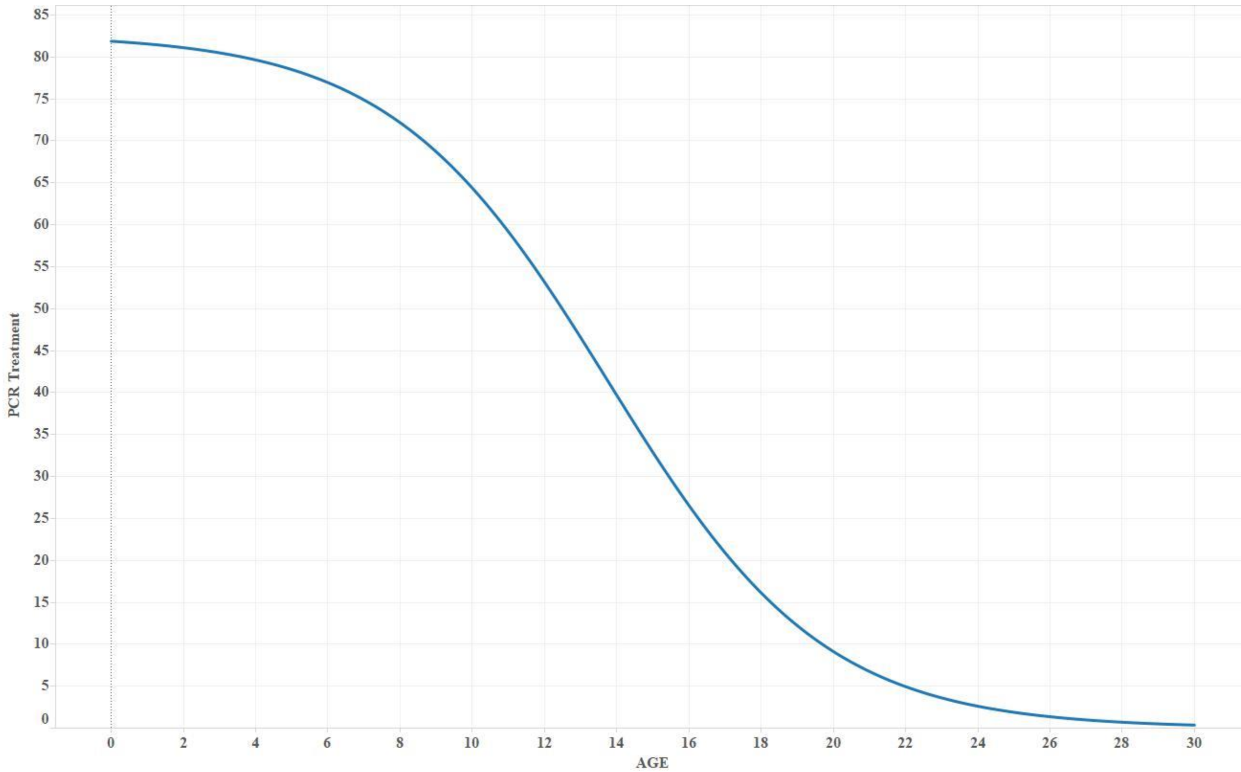

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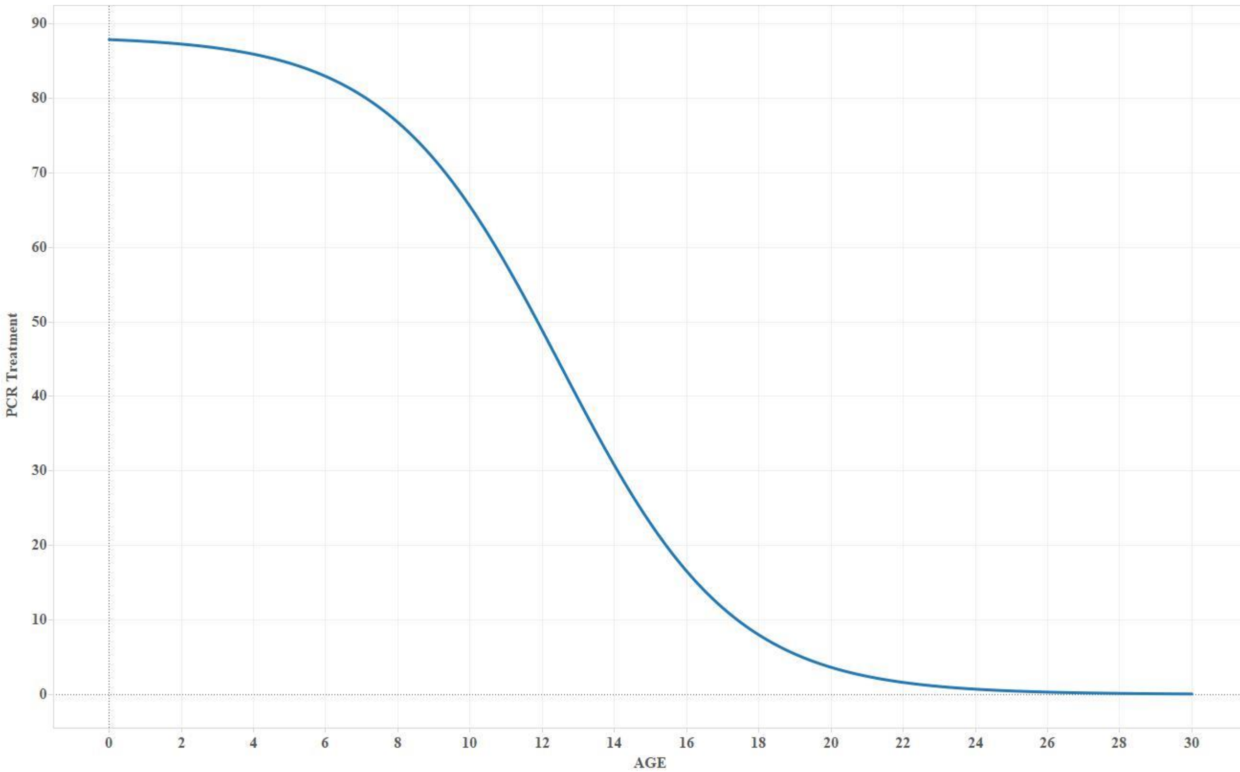

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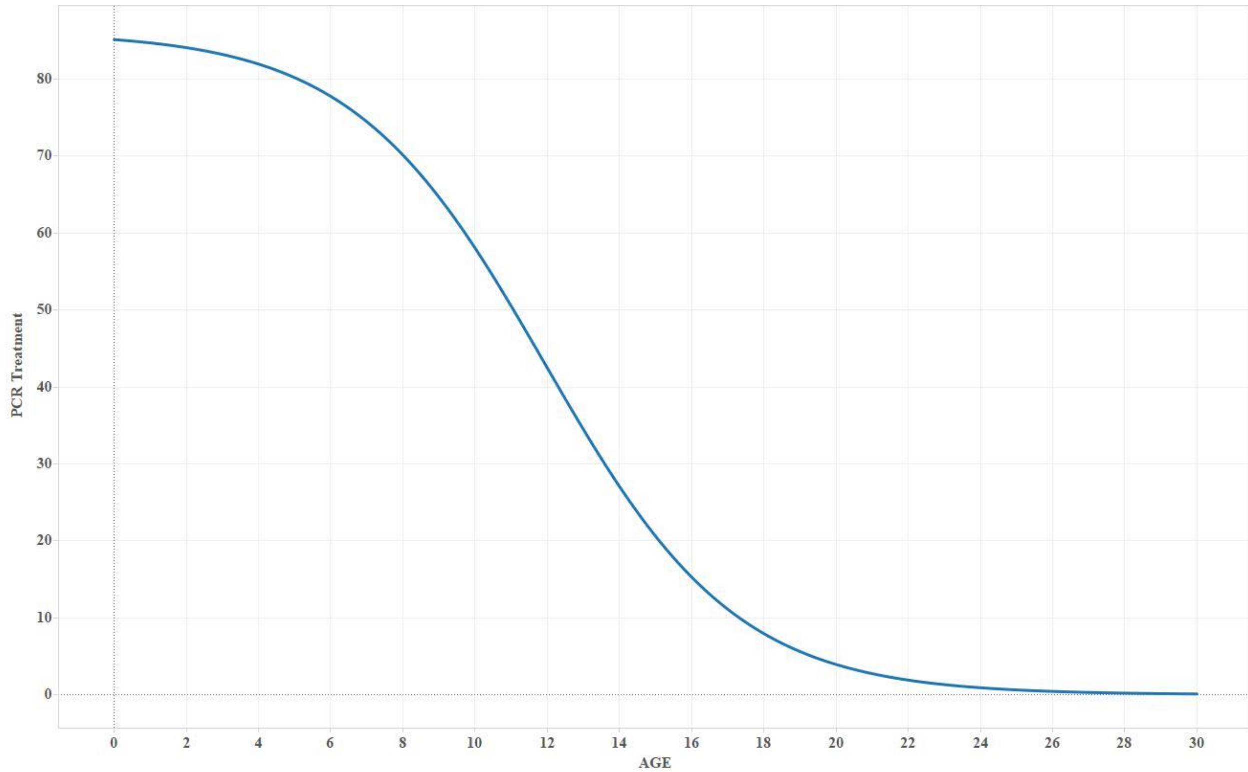

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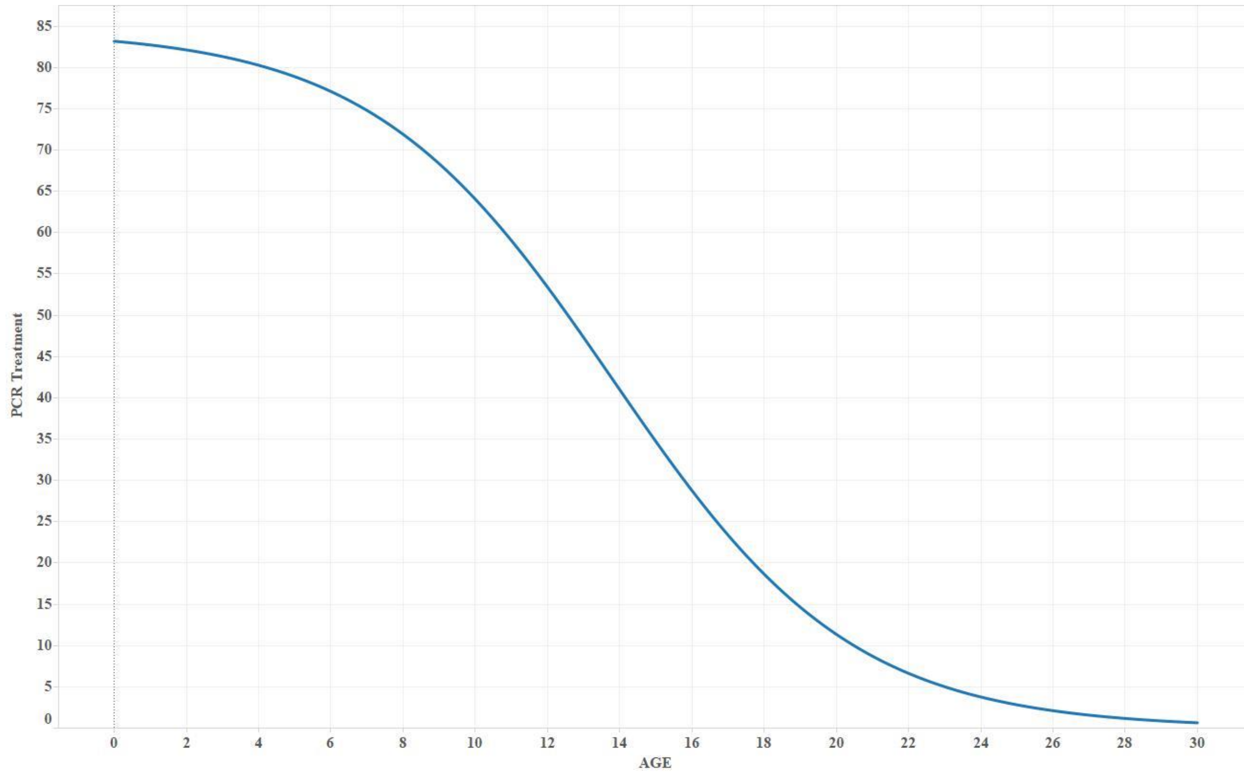

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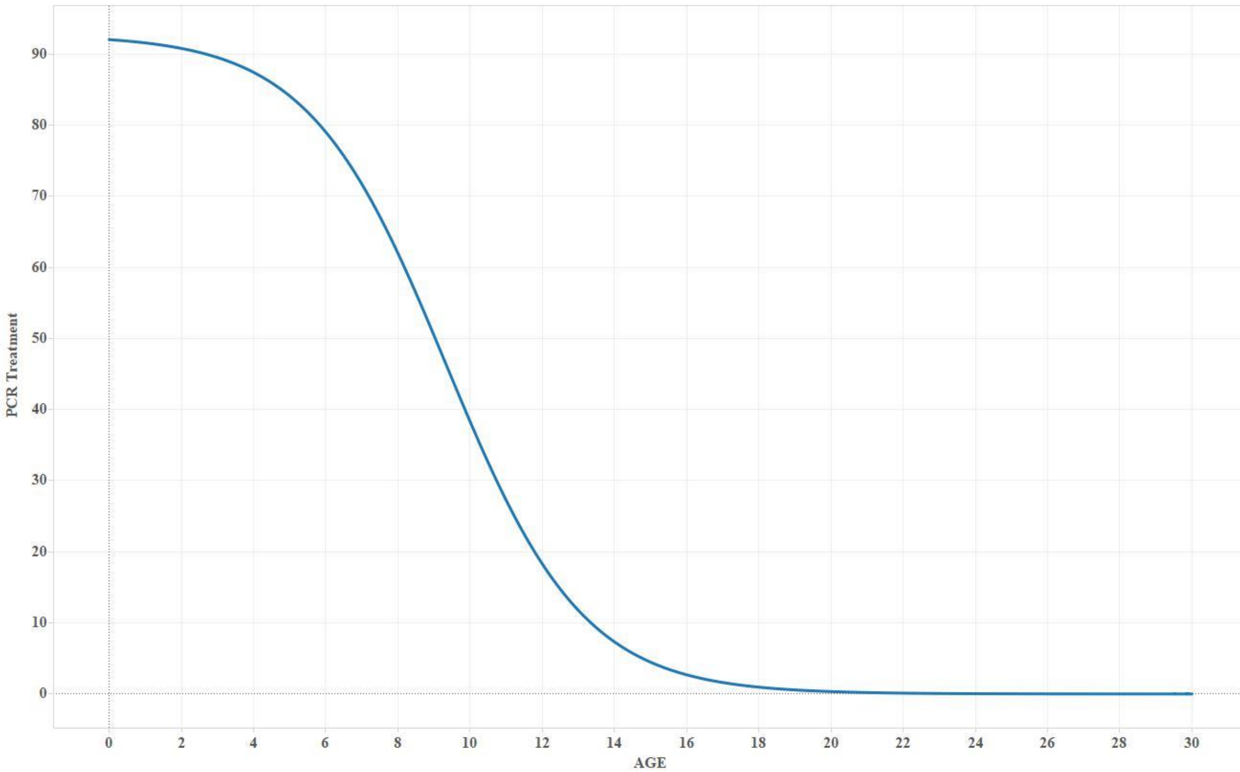

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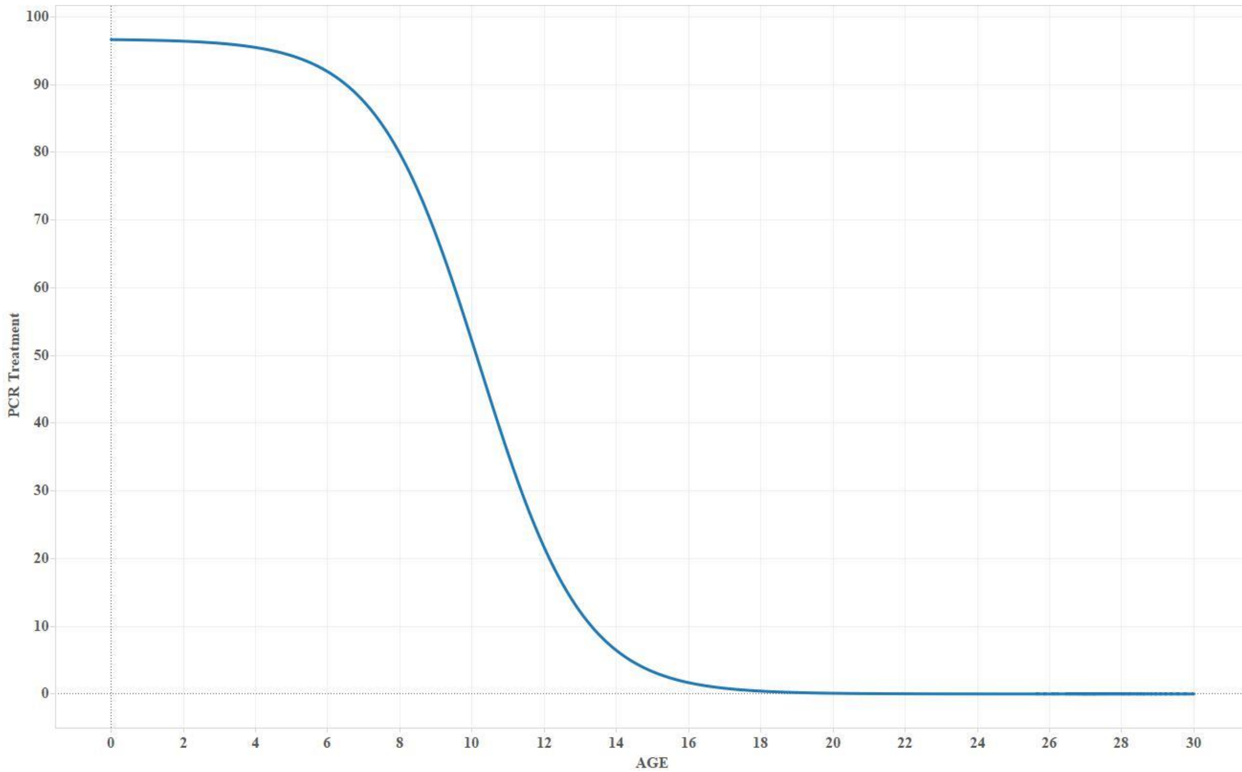

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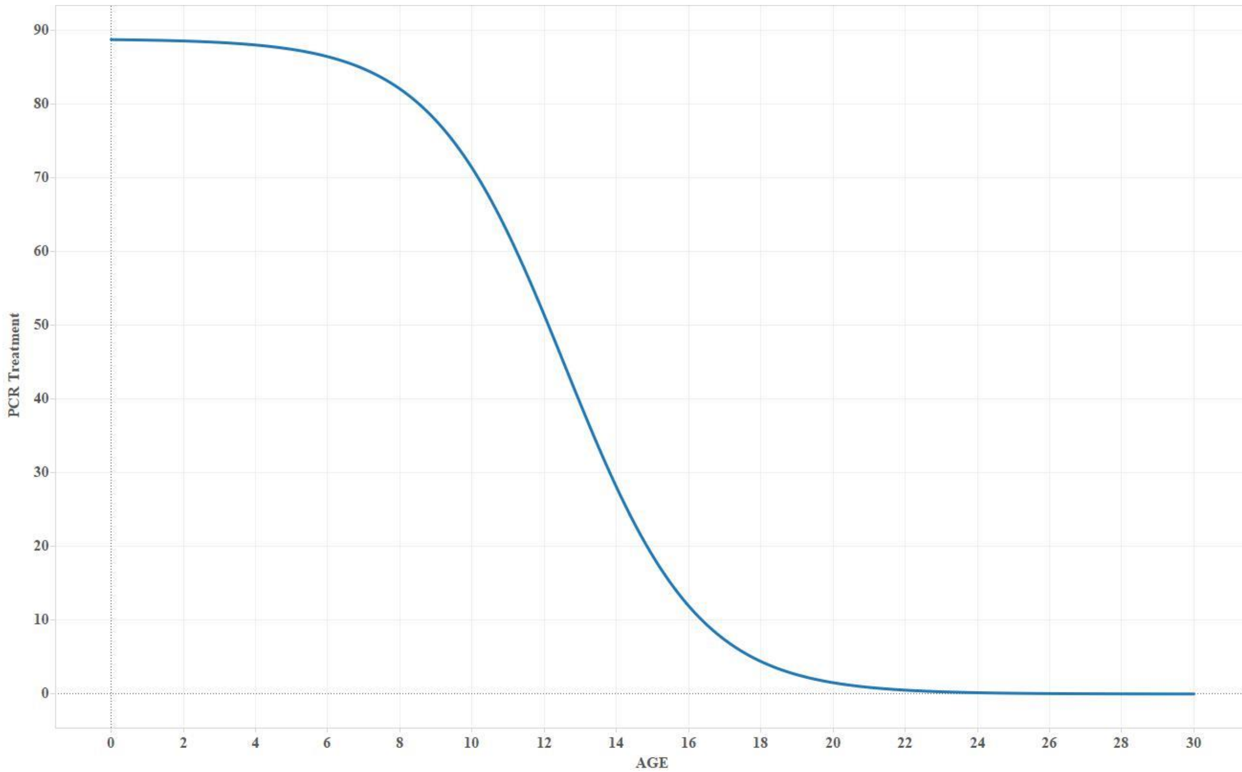

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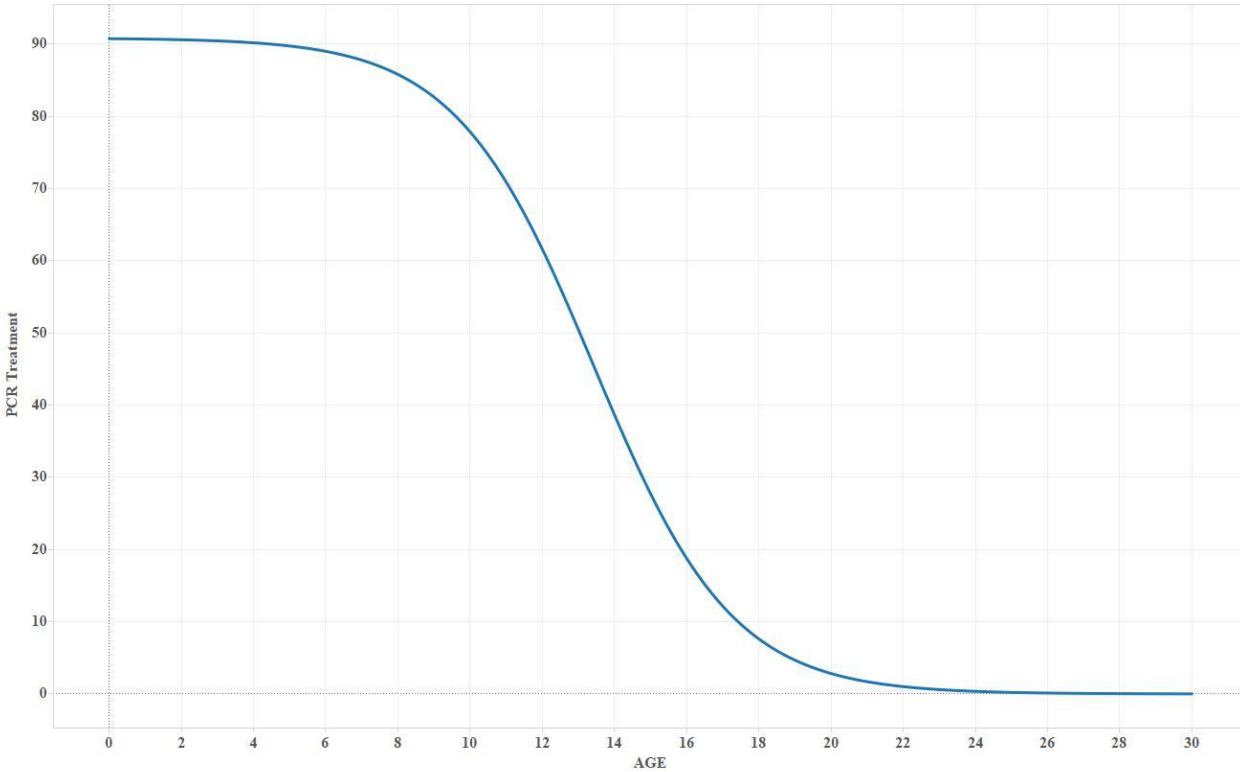

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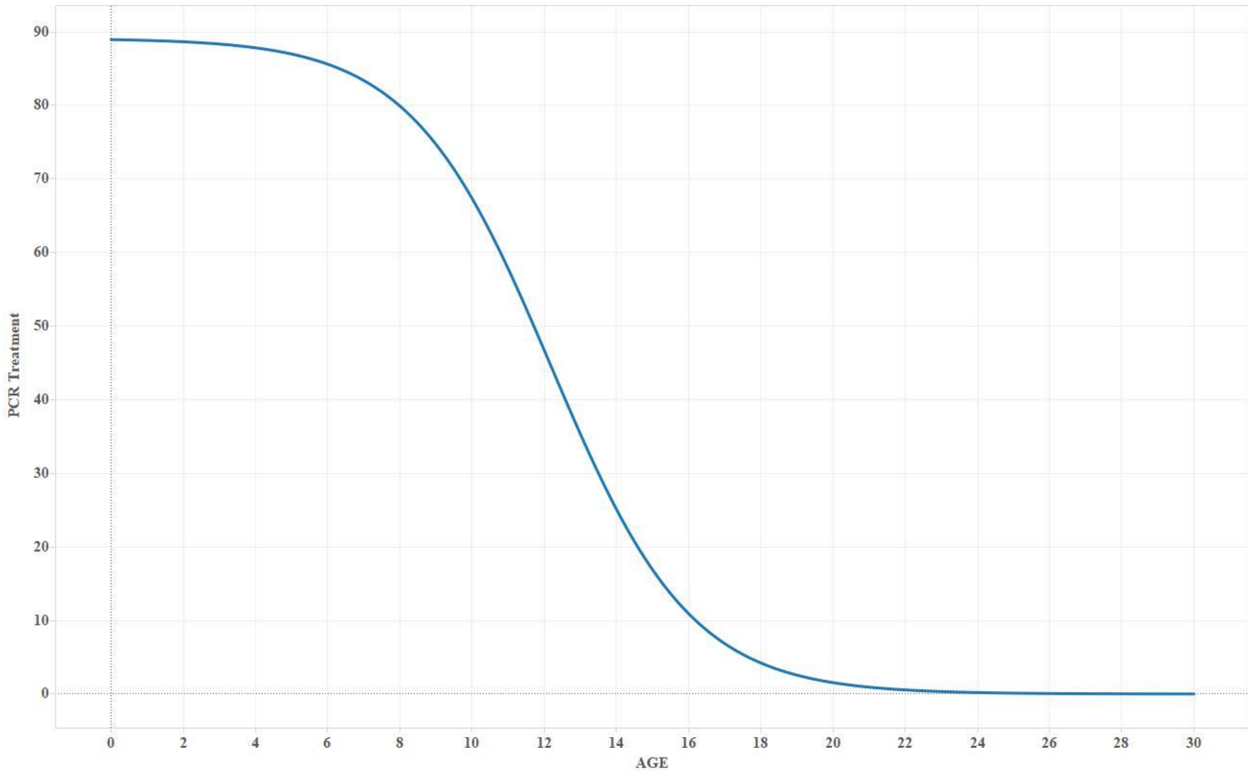

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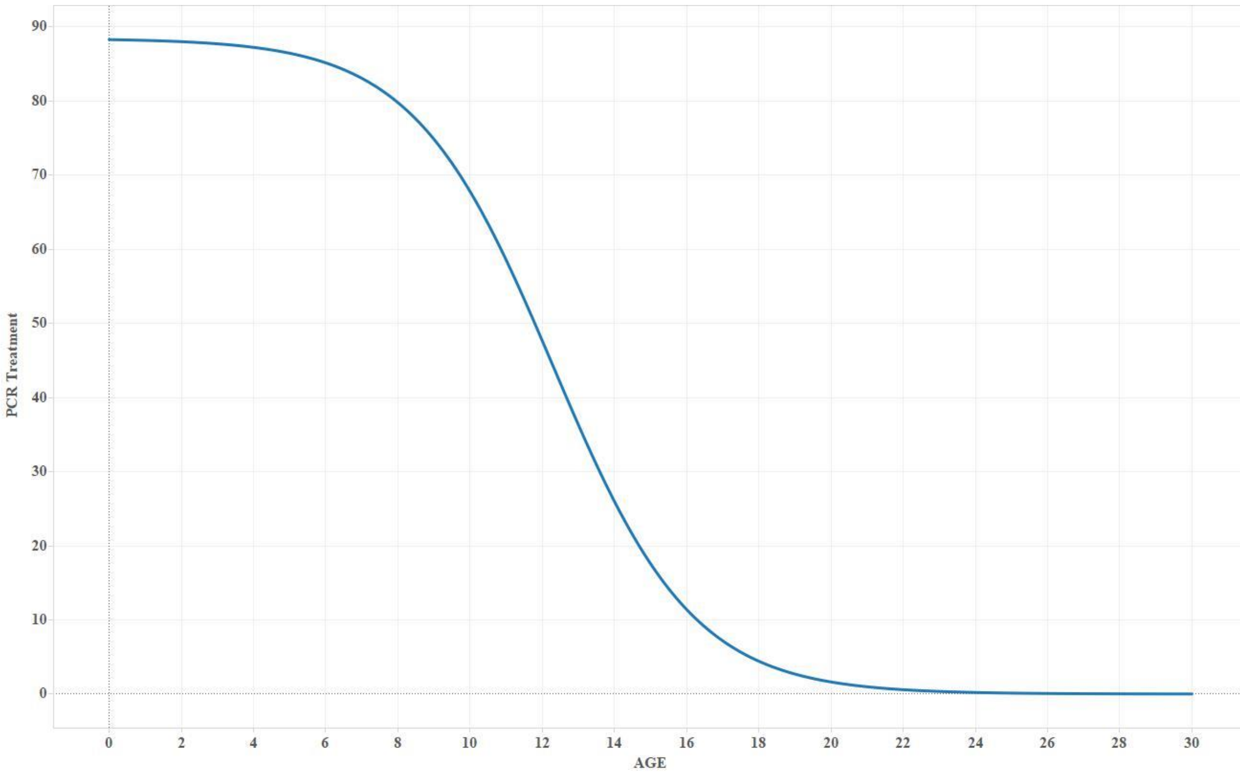

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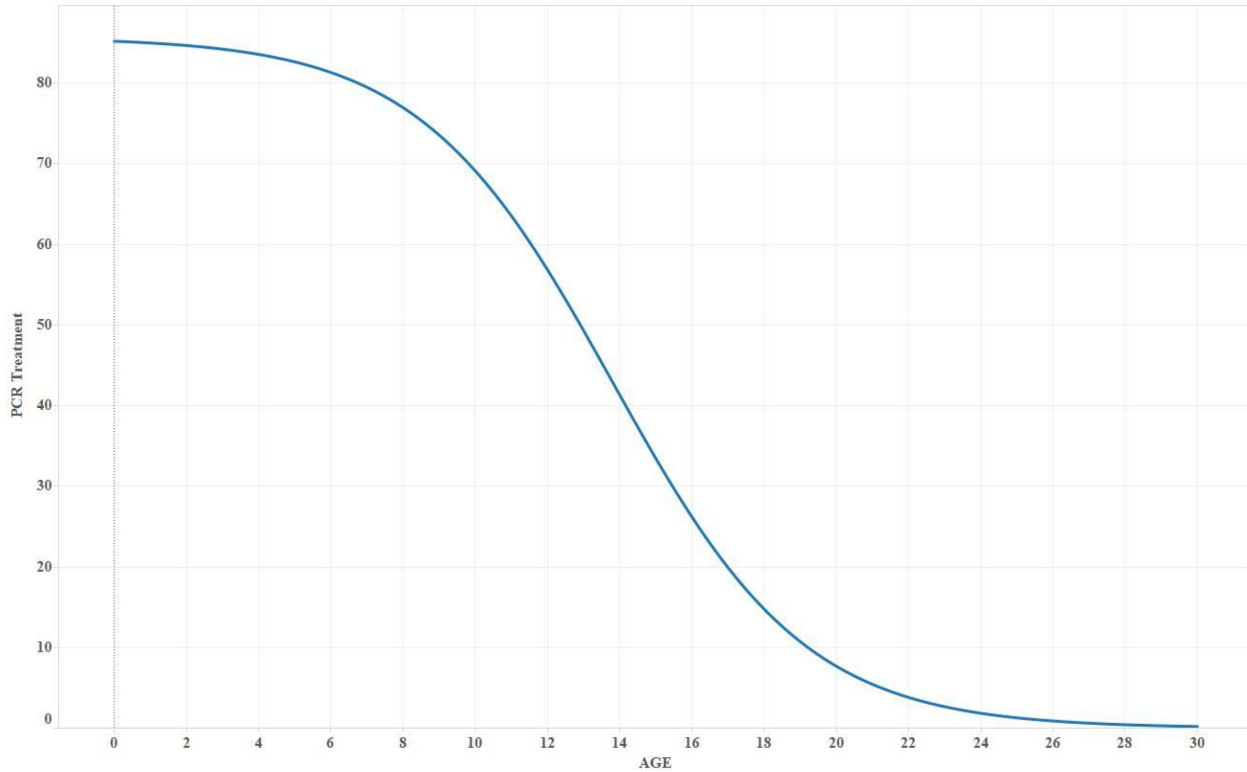

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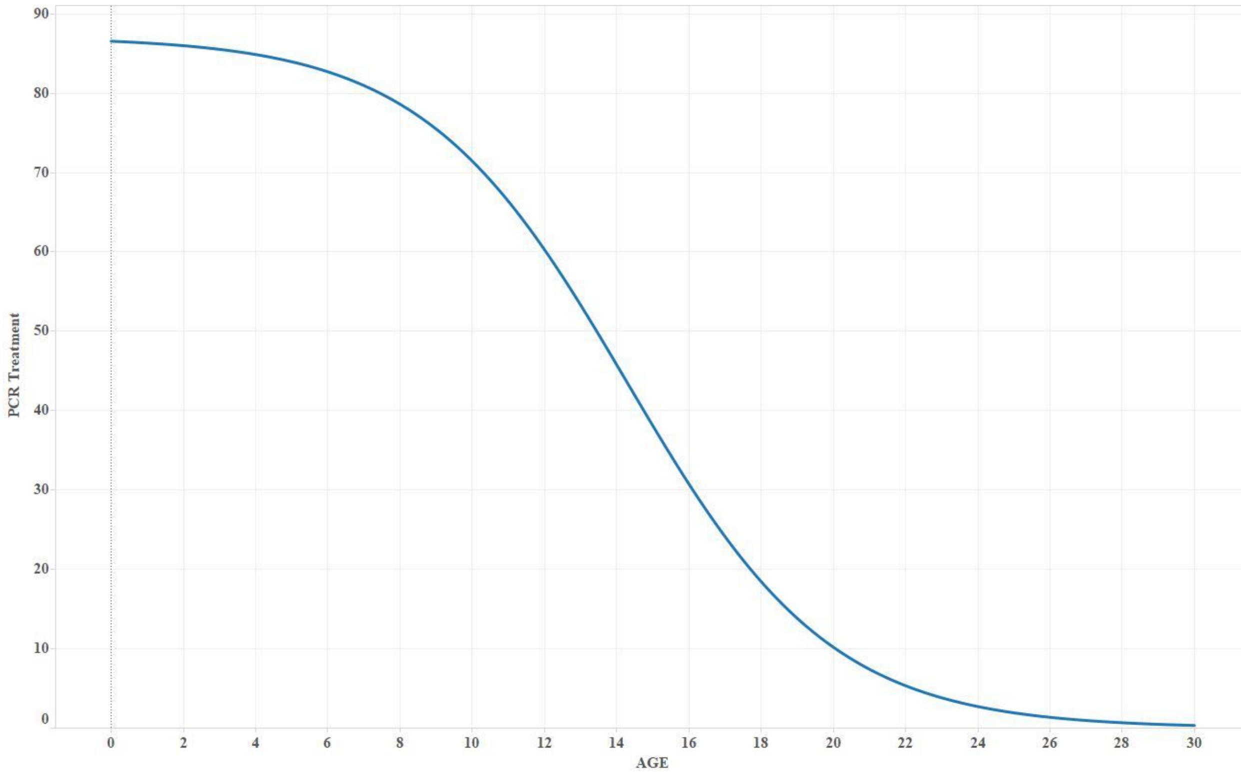

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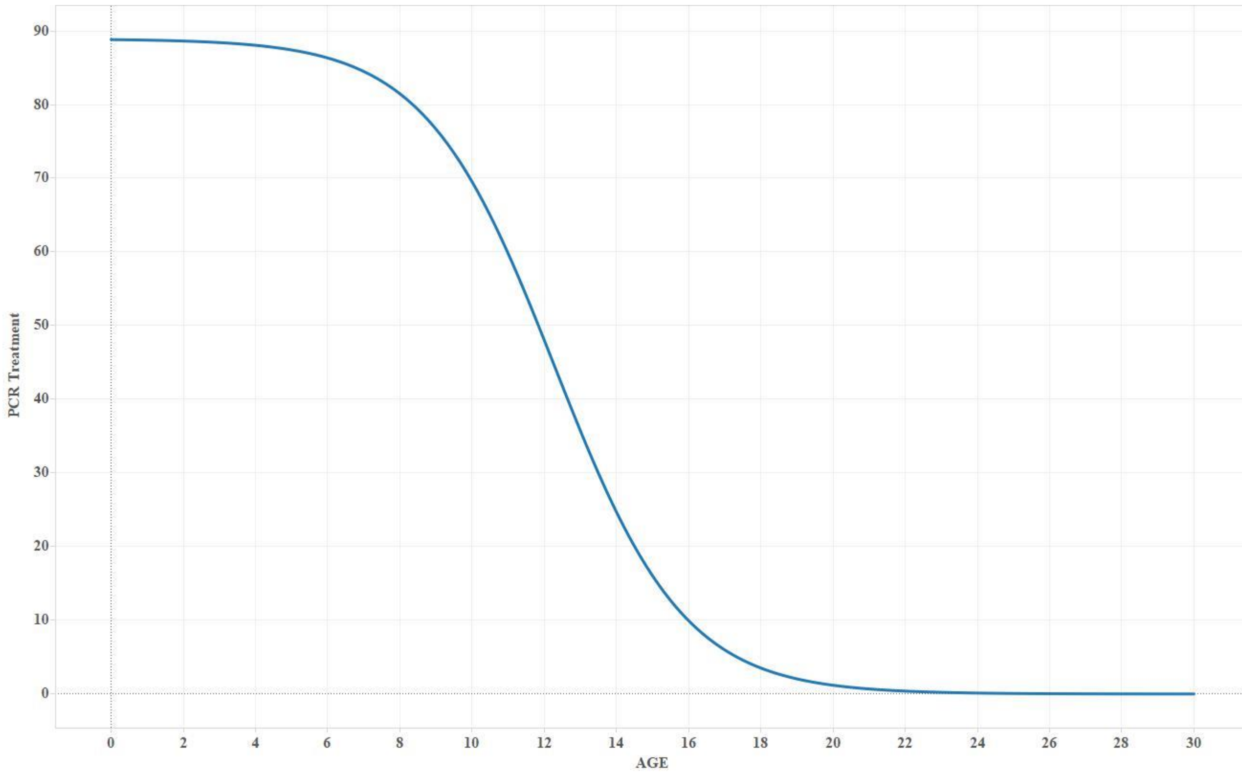

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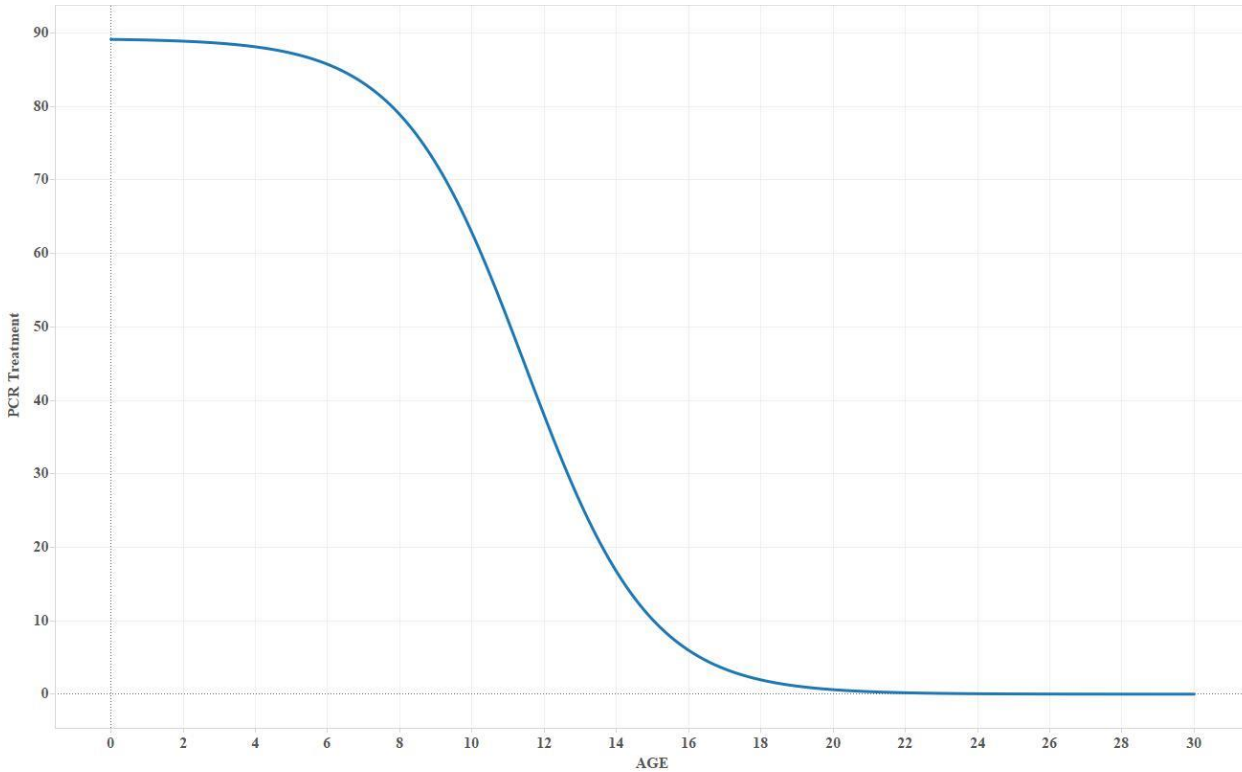

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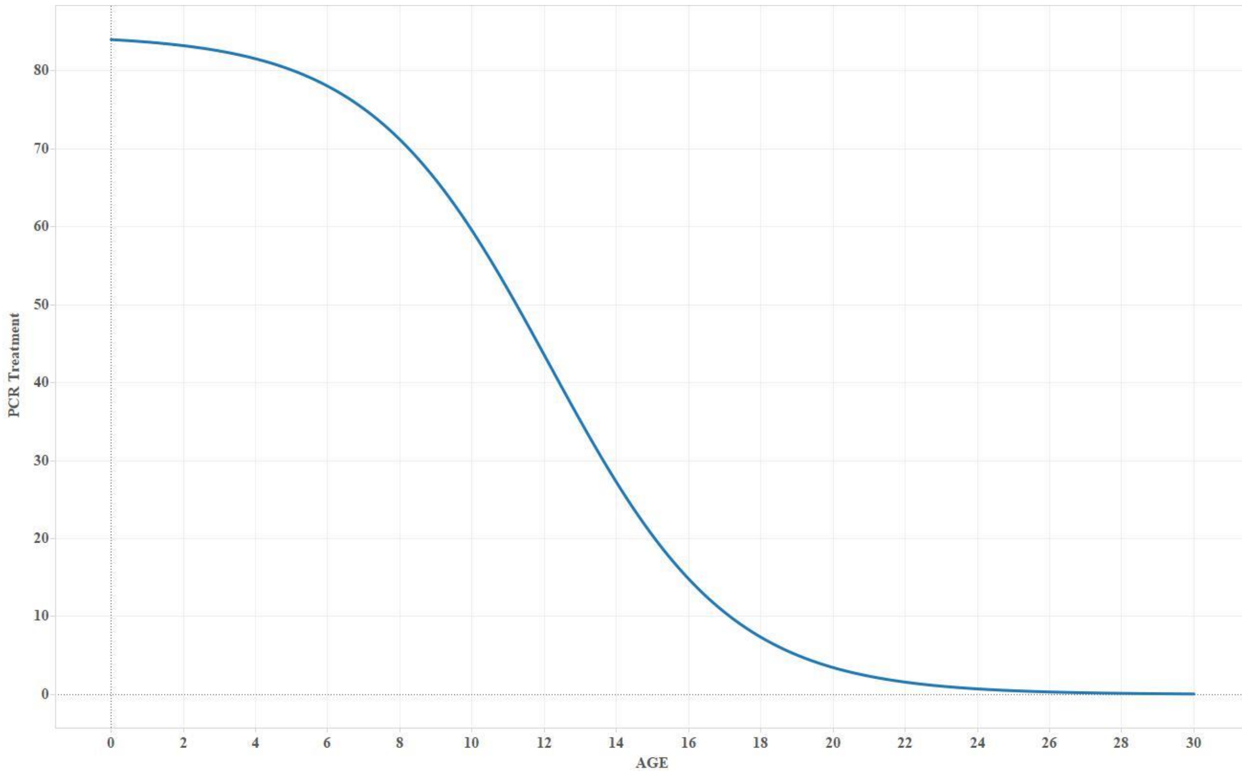

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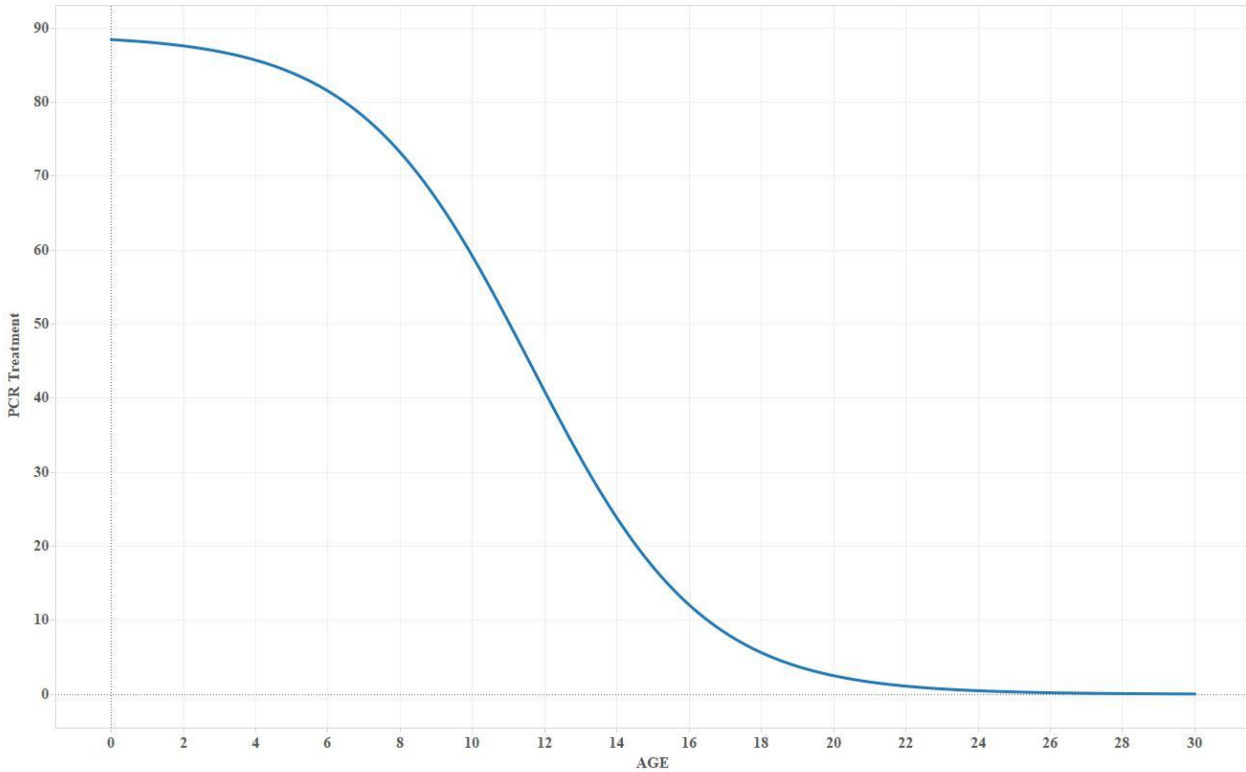

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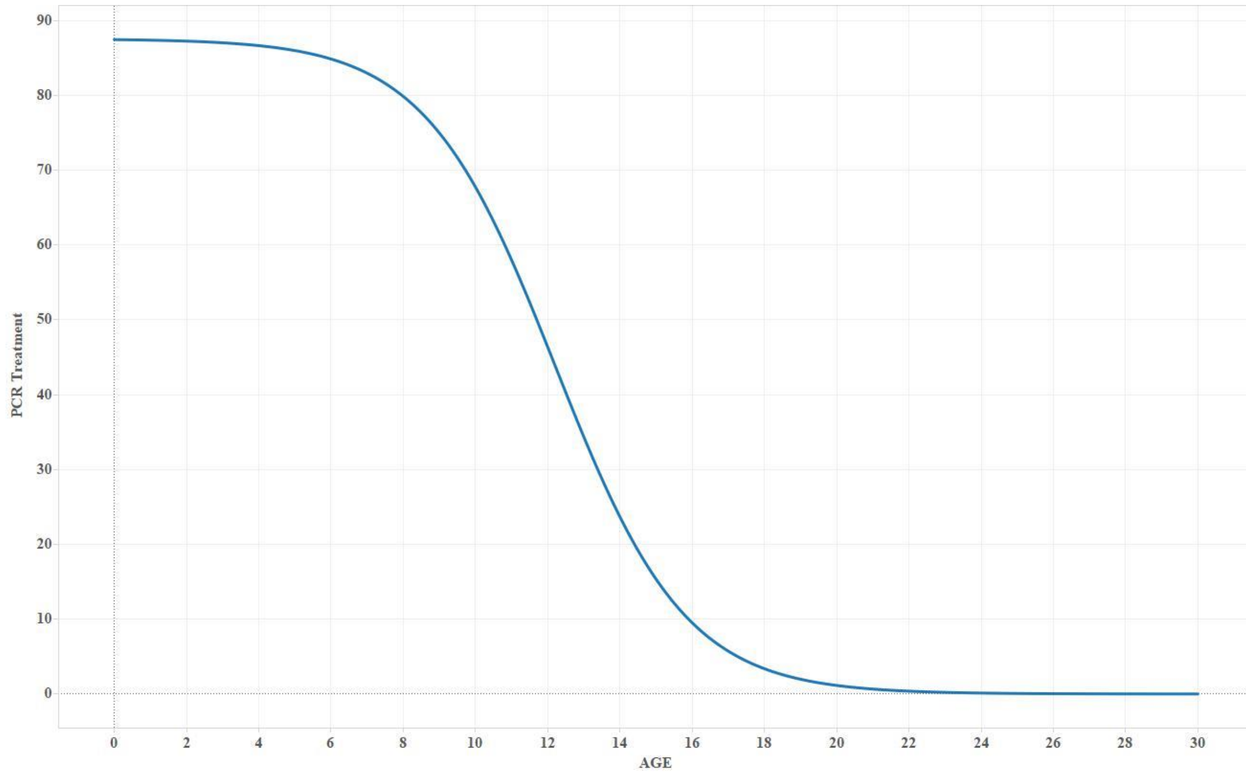

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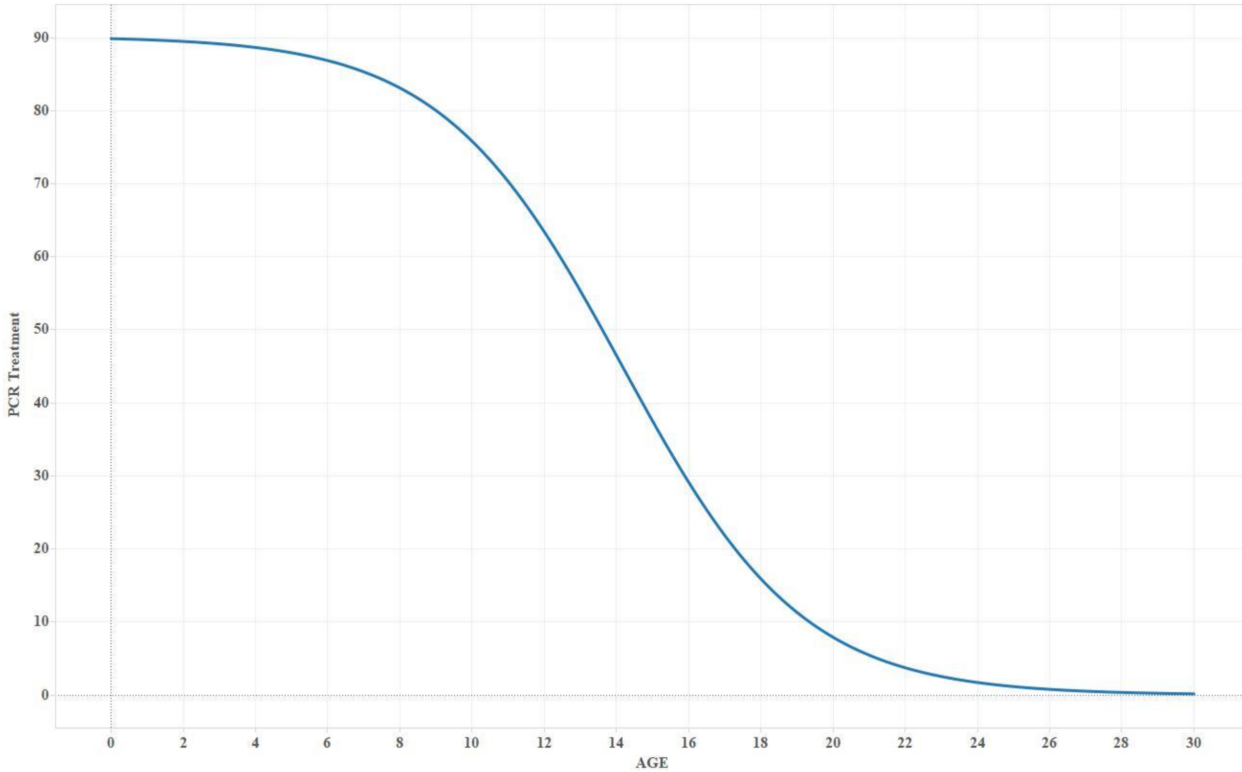

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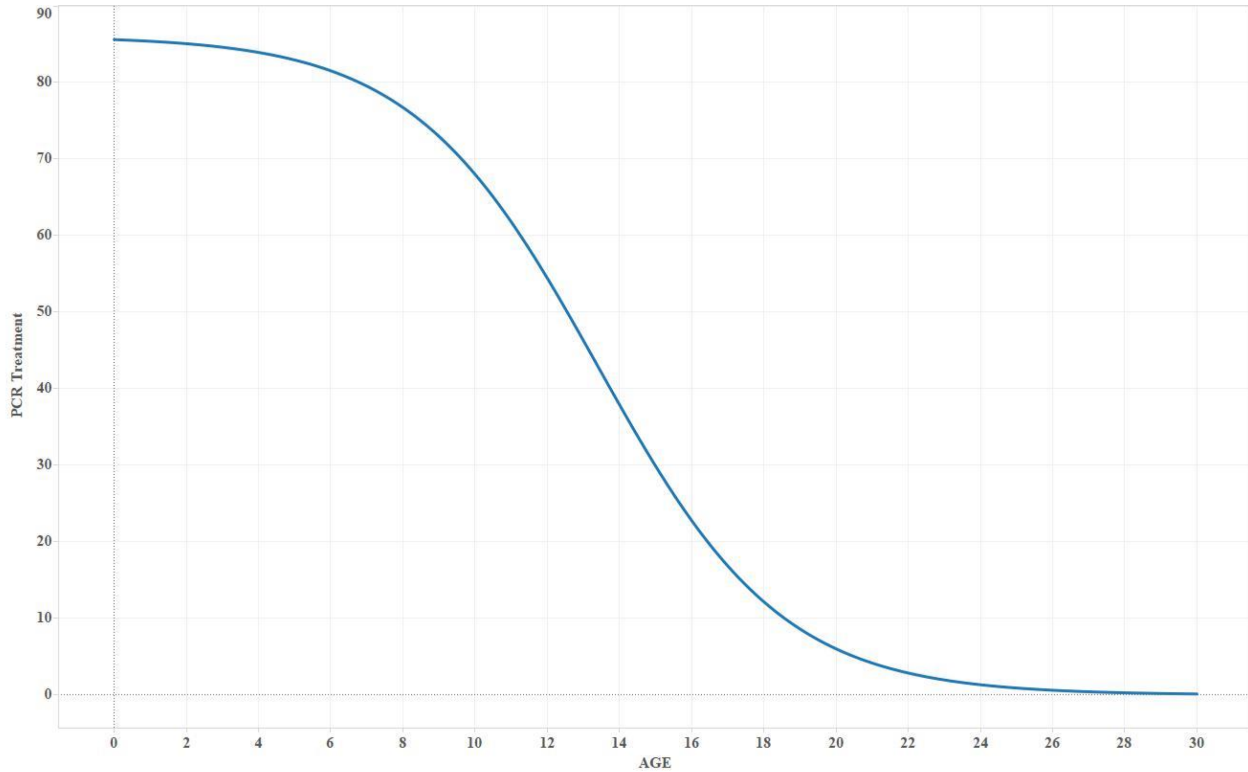

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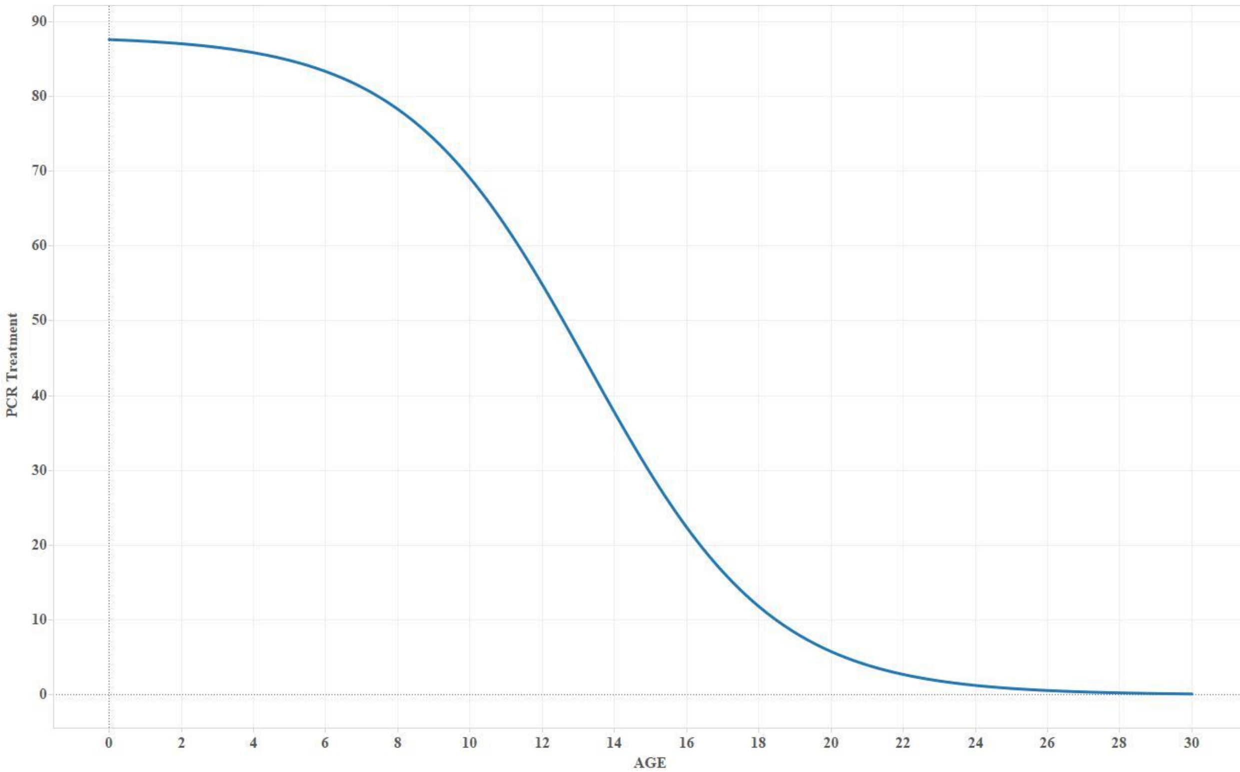

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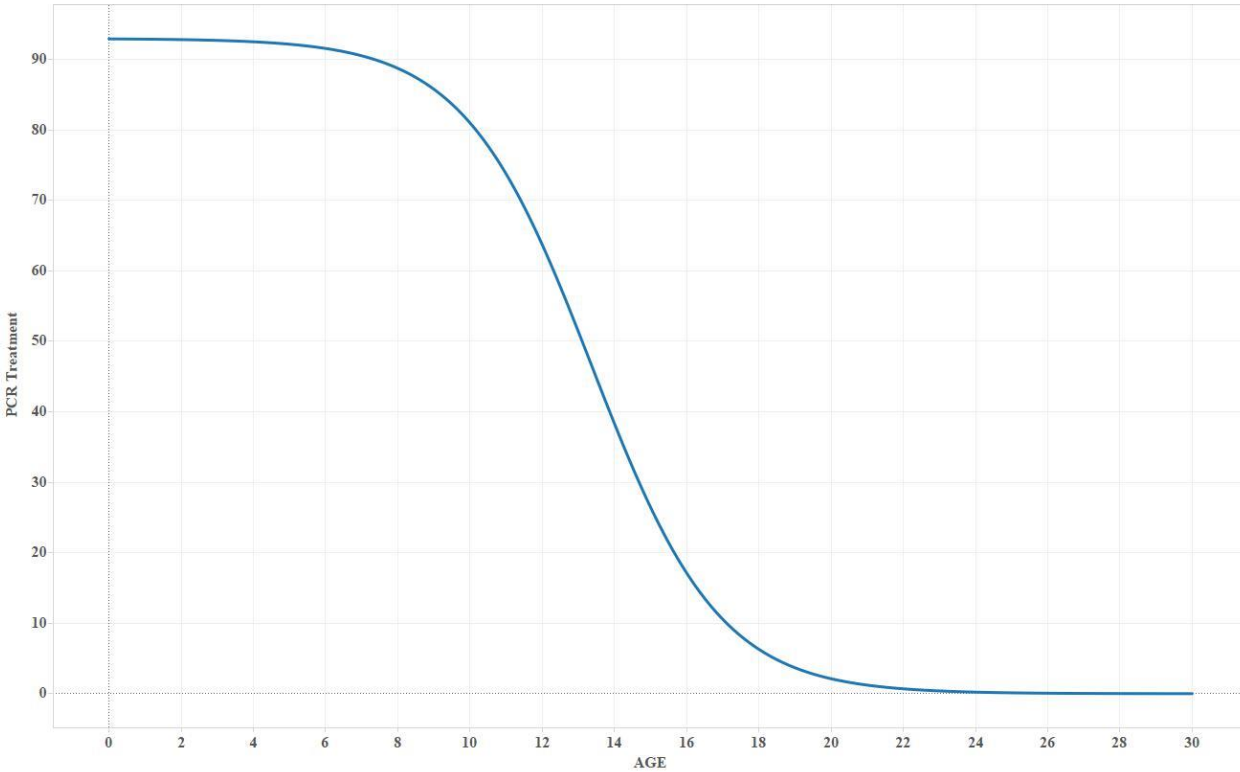
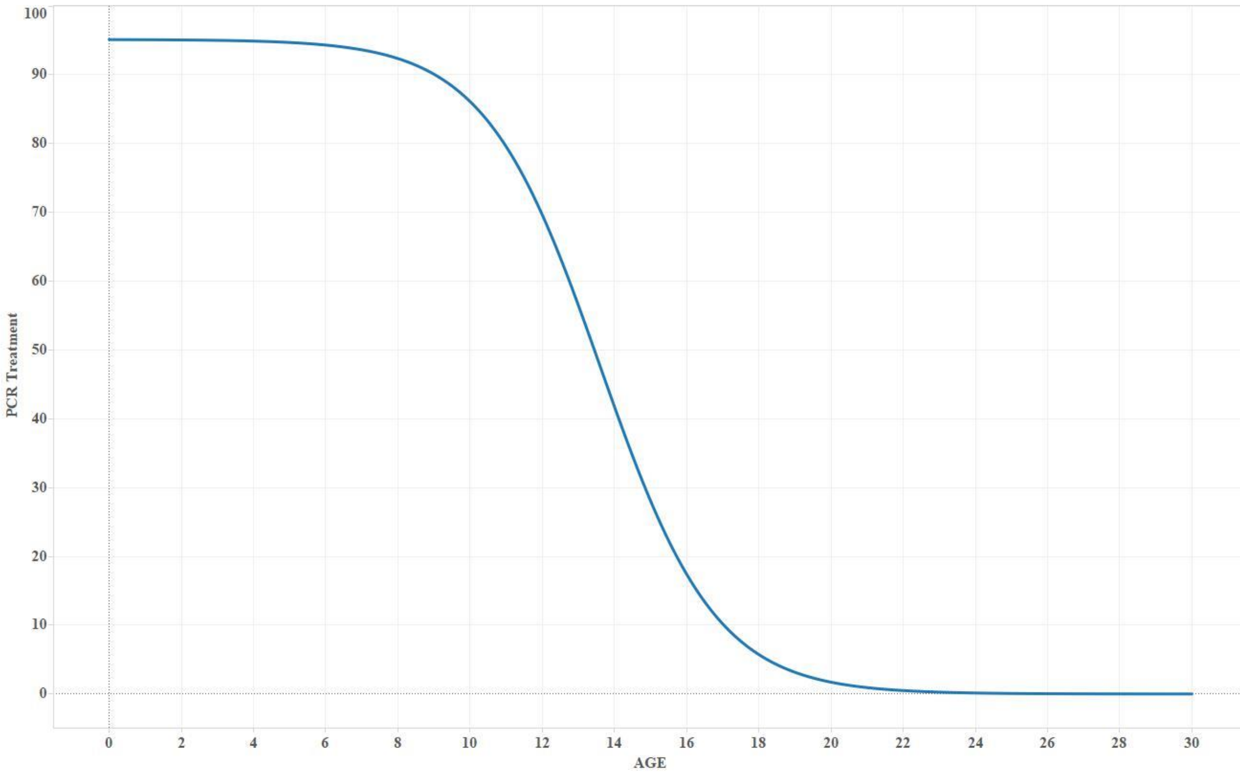


Interstate 0-50k (Resurface)



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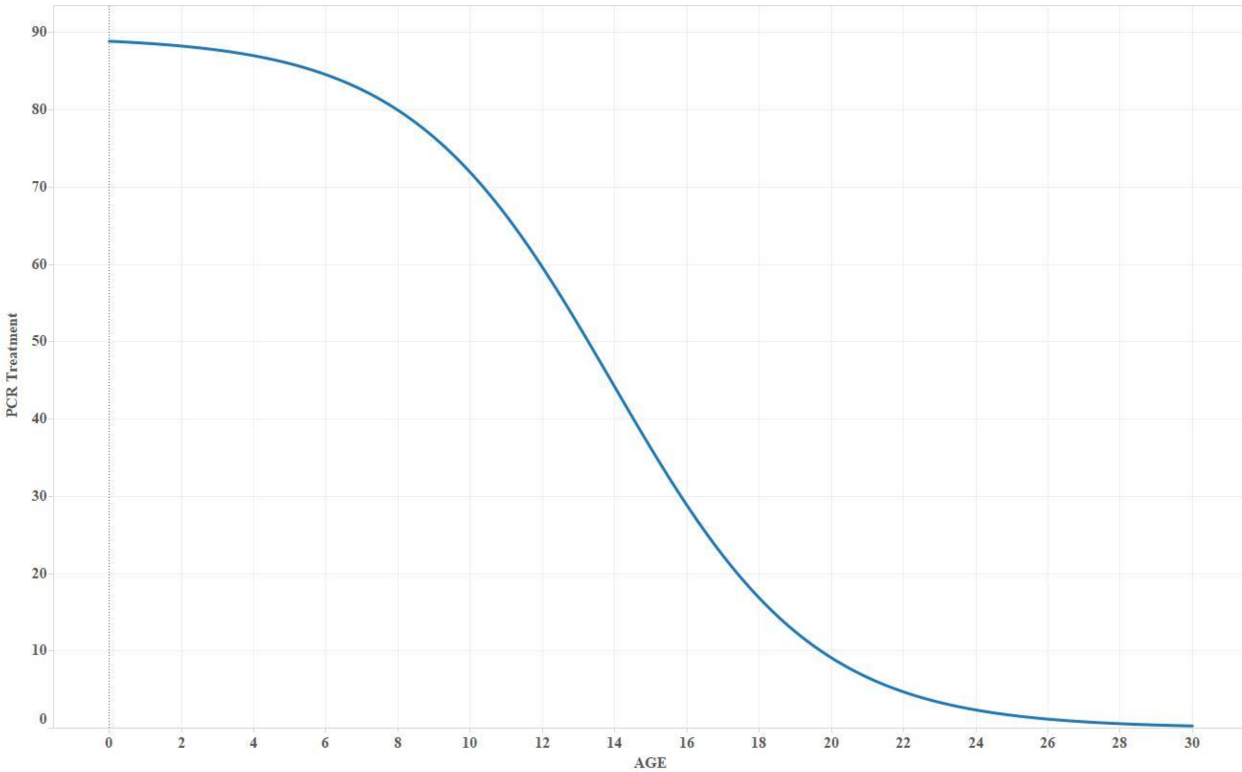

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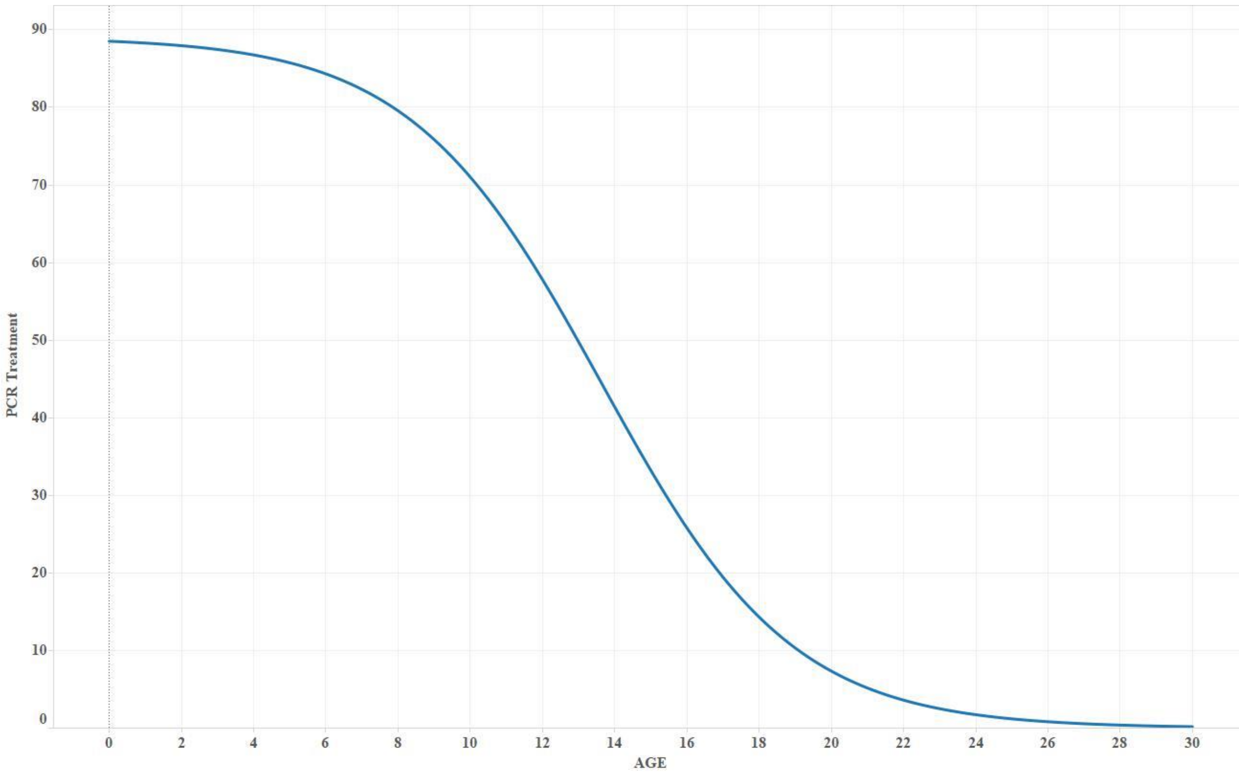

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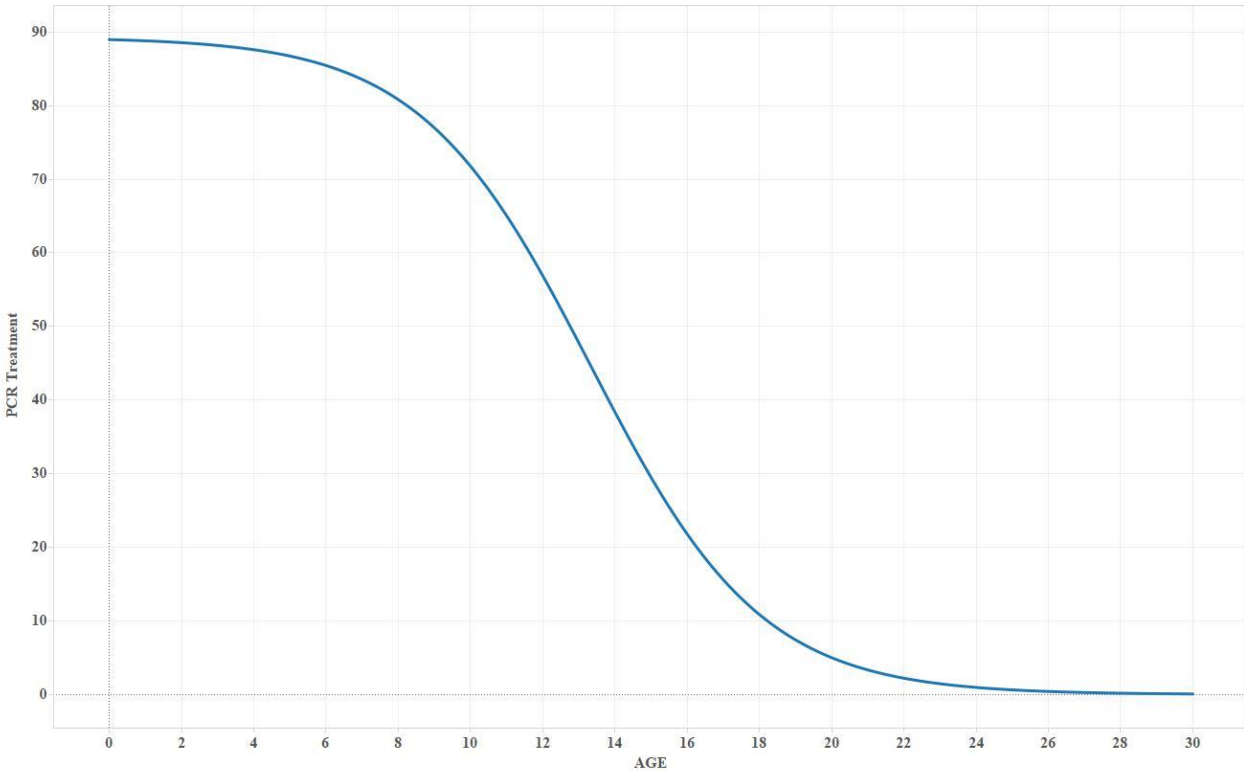
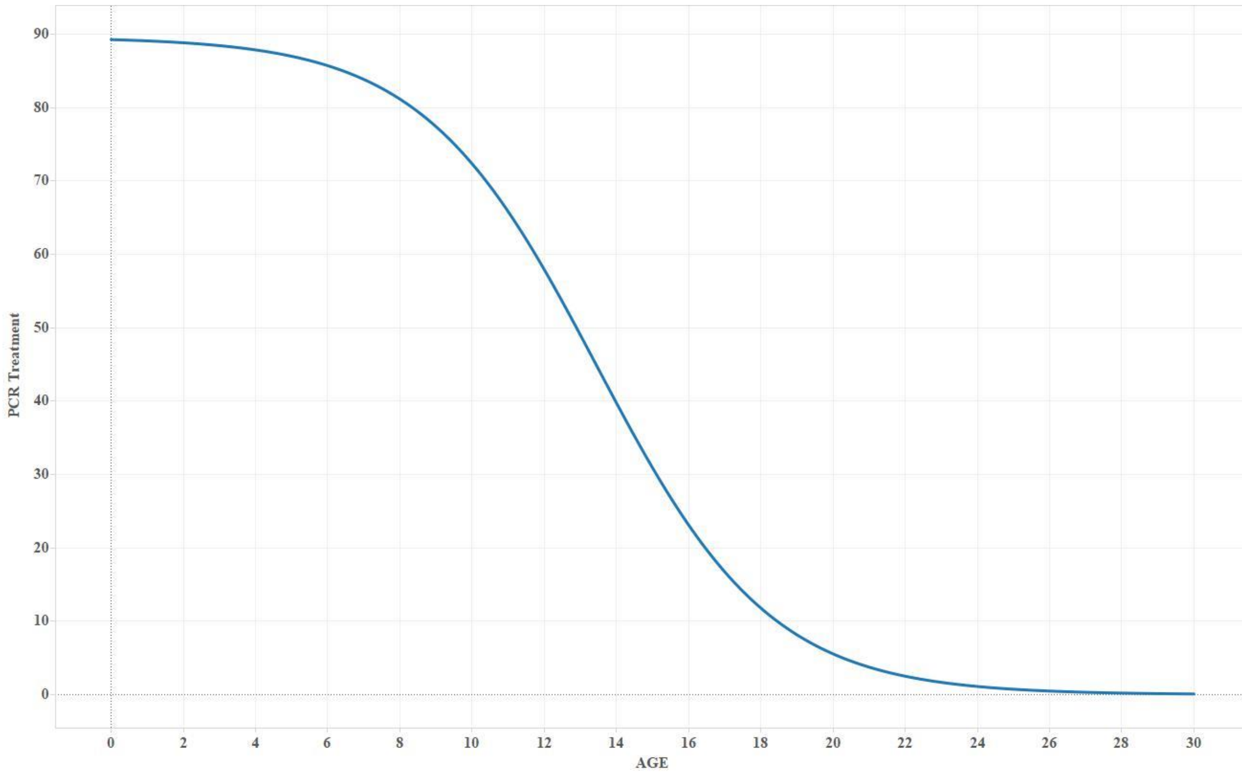


US 15-30k (Resurface)



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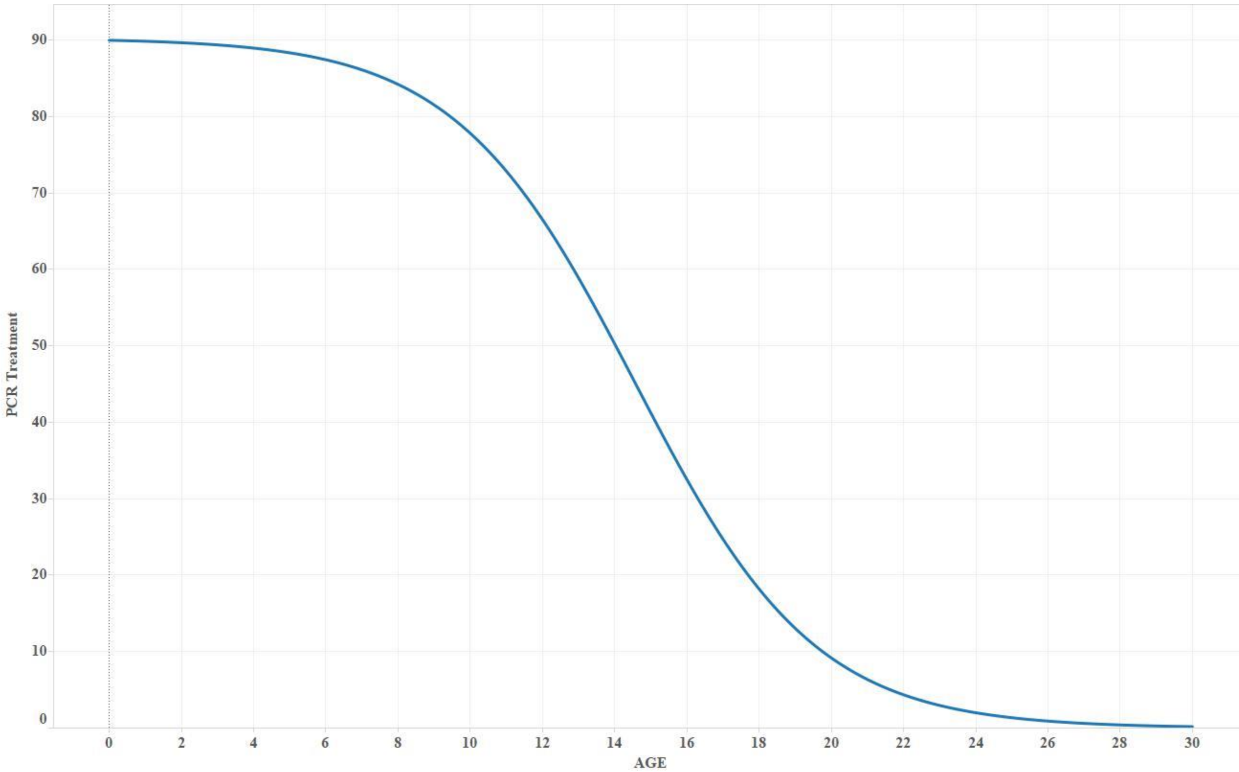

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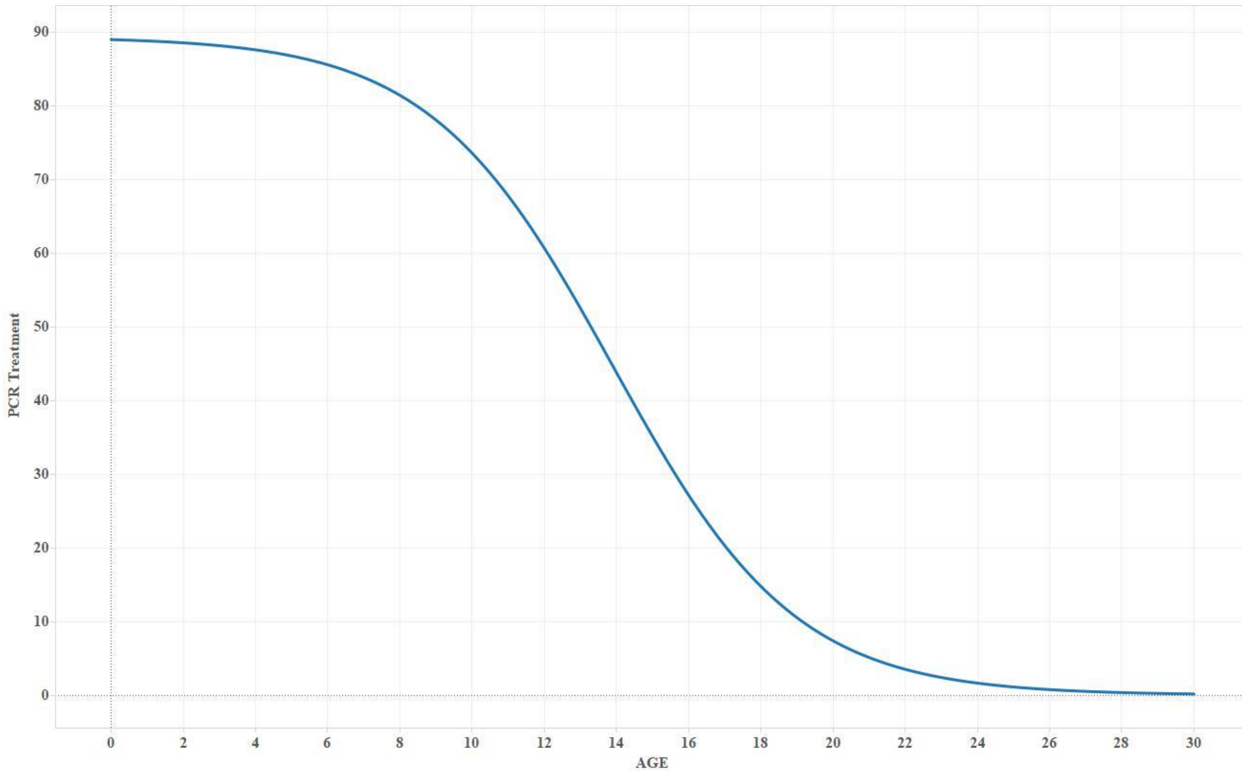

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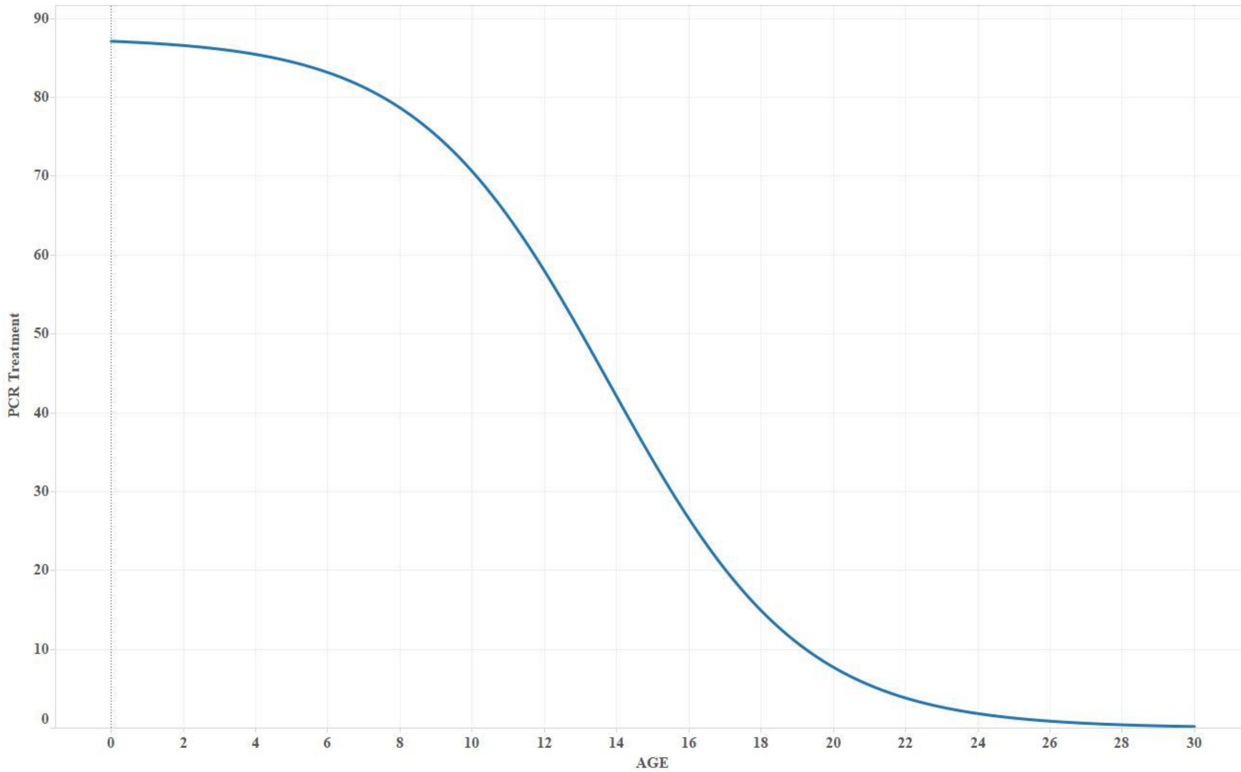

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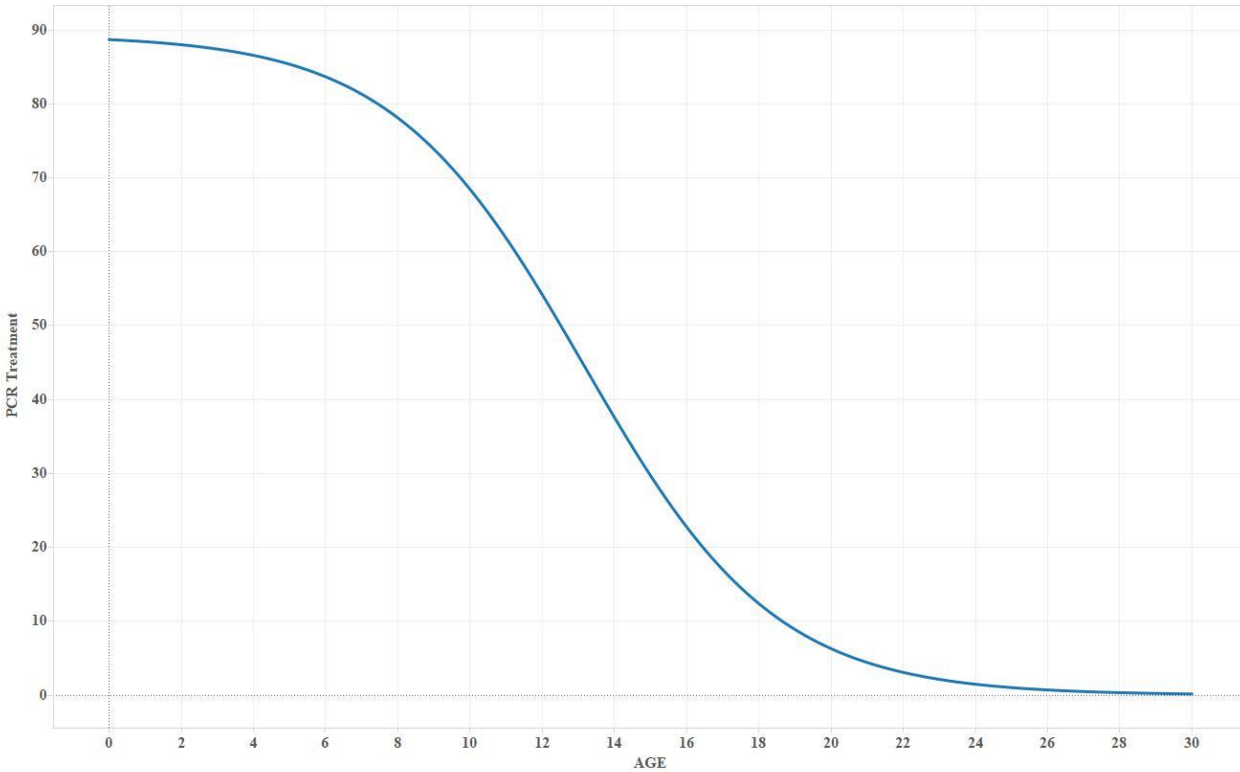

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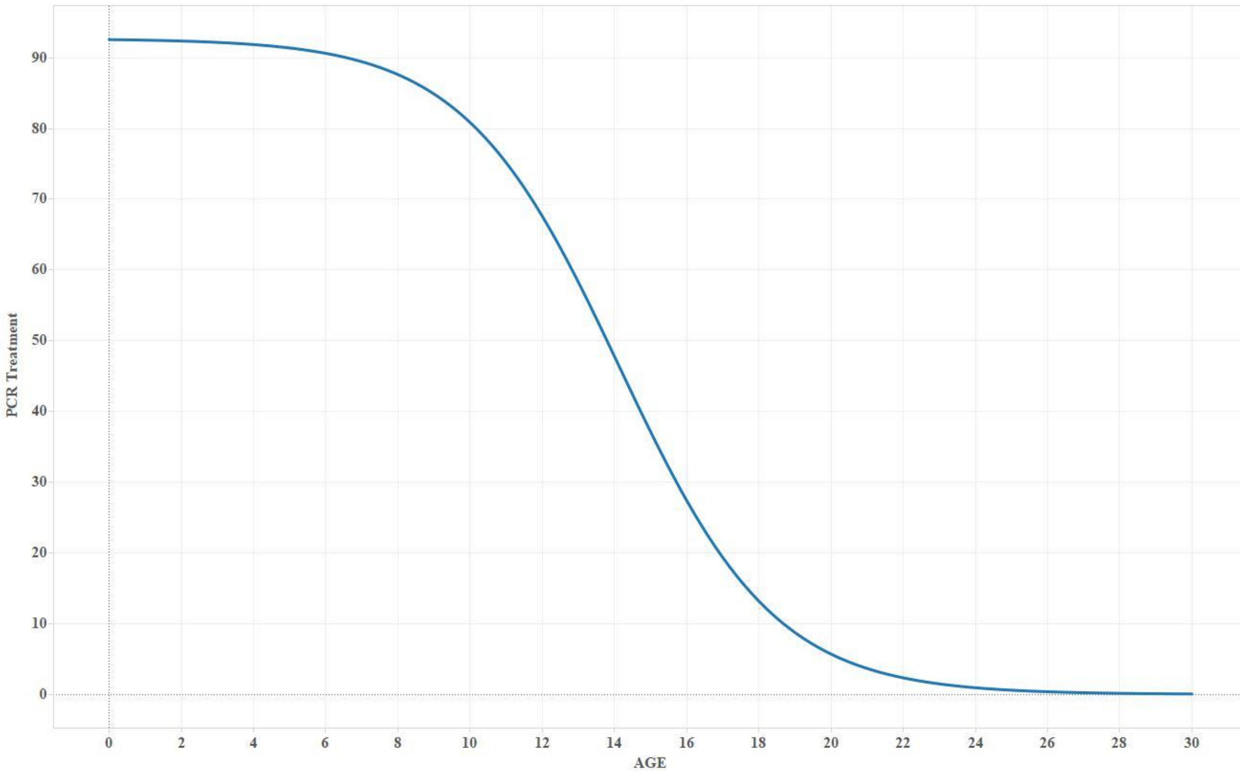

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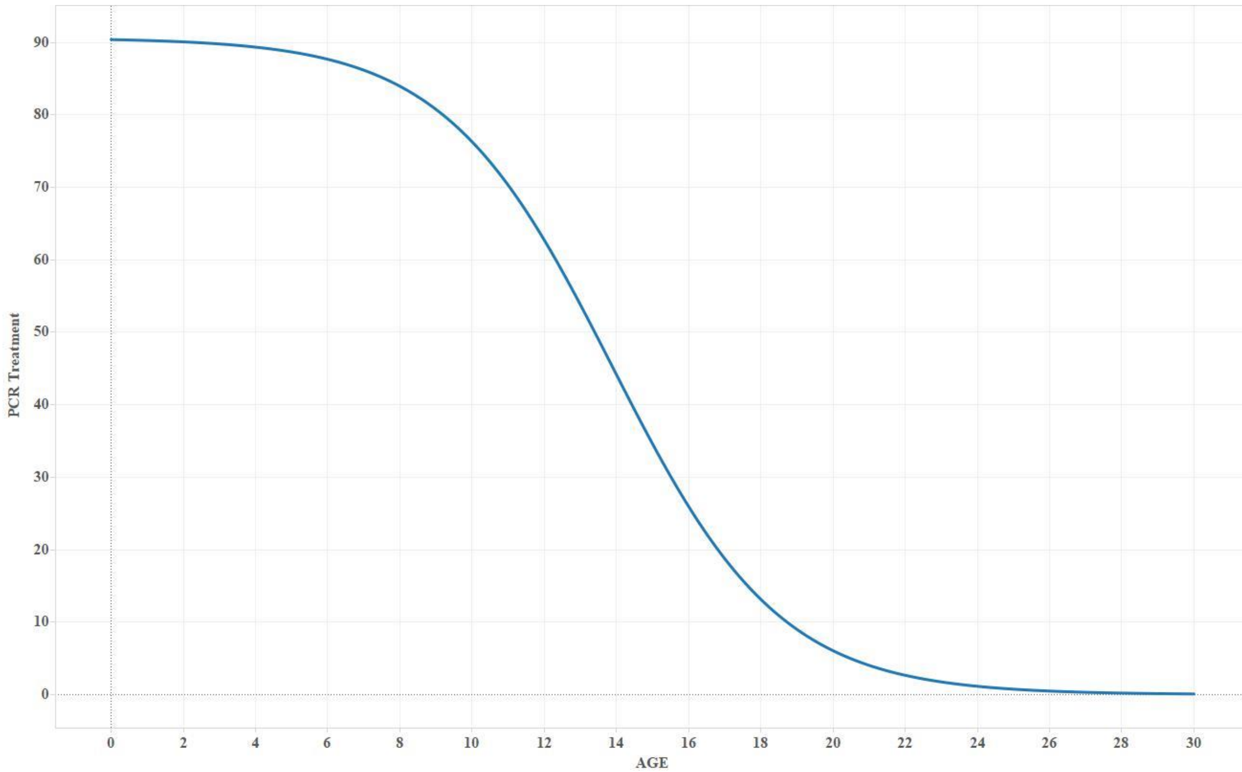

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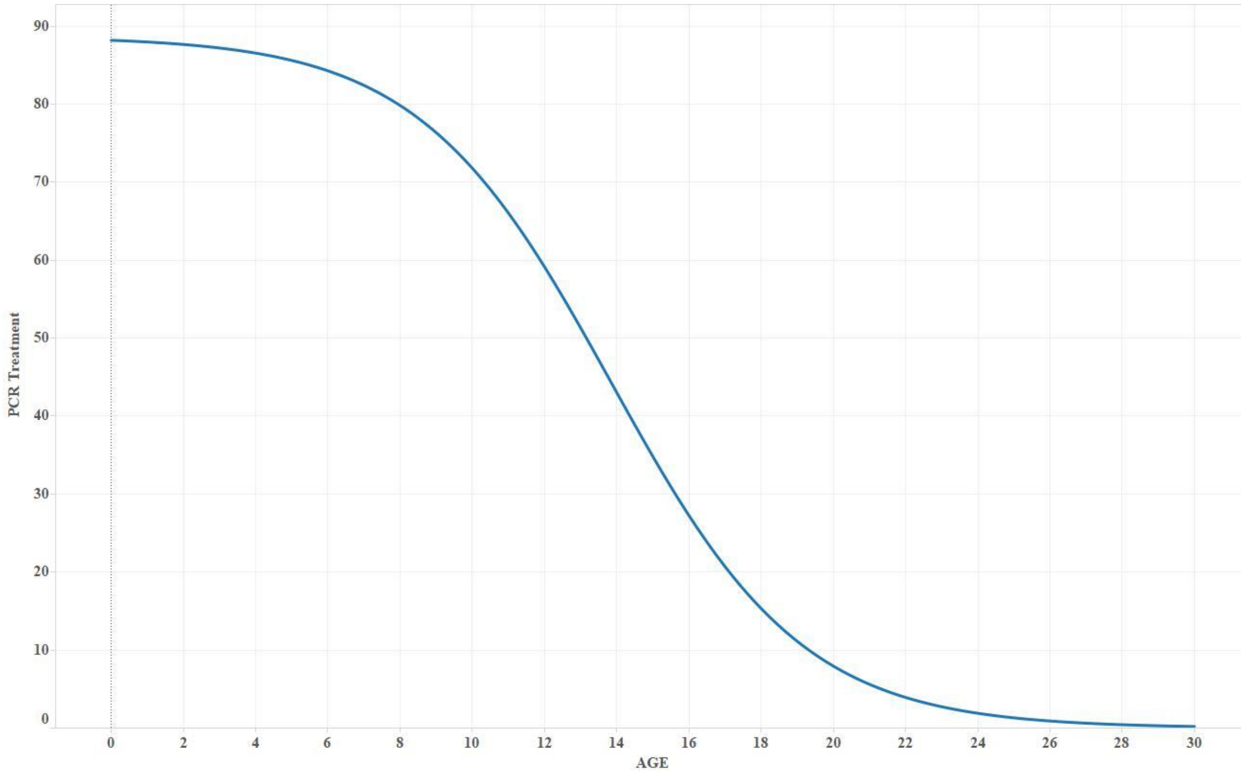

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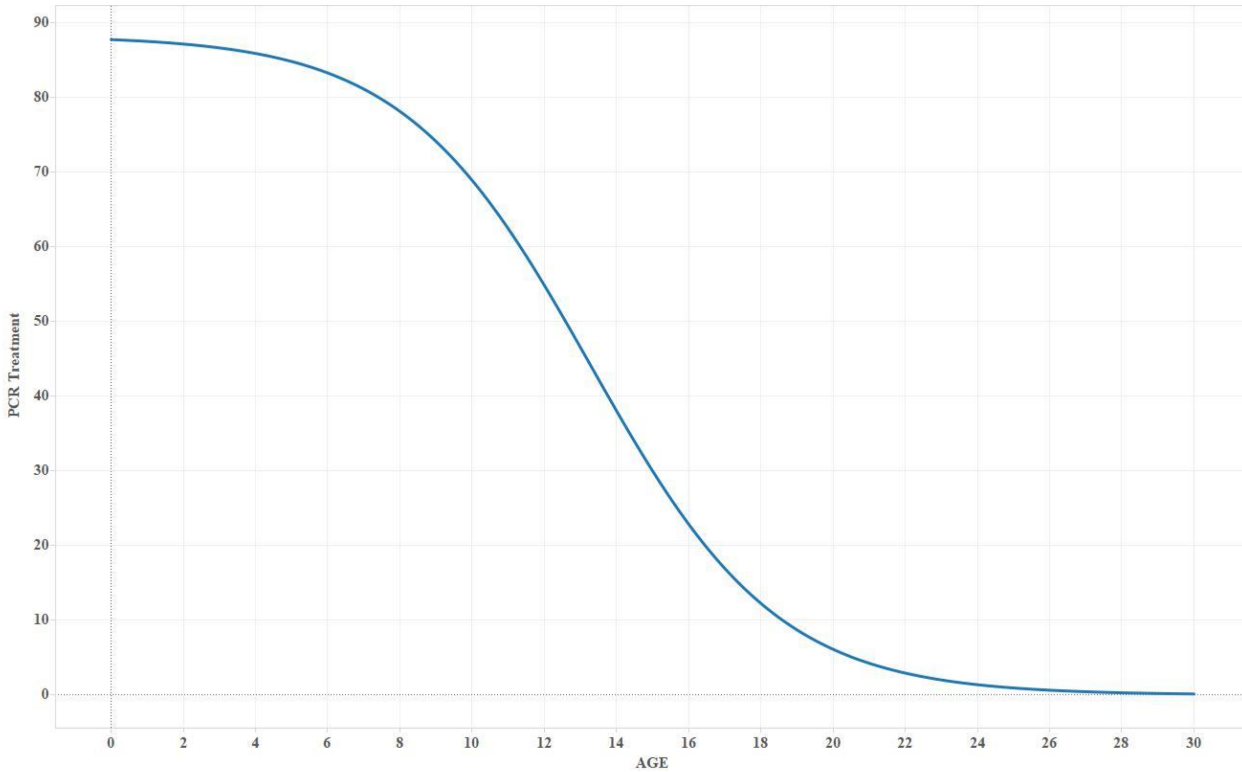
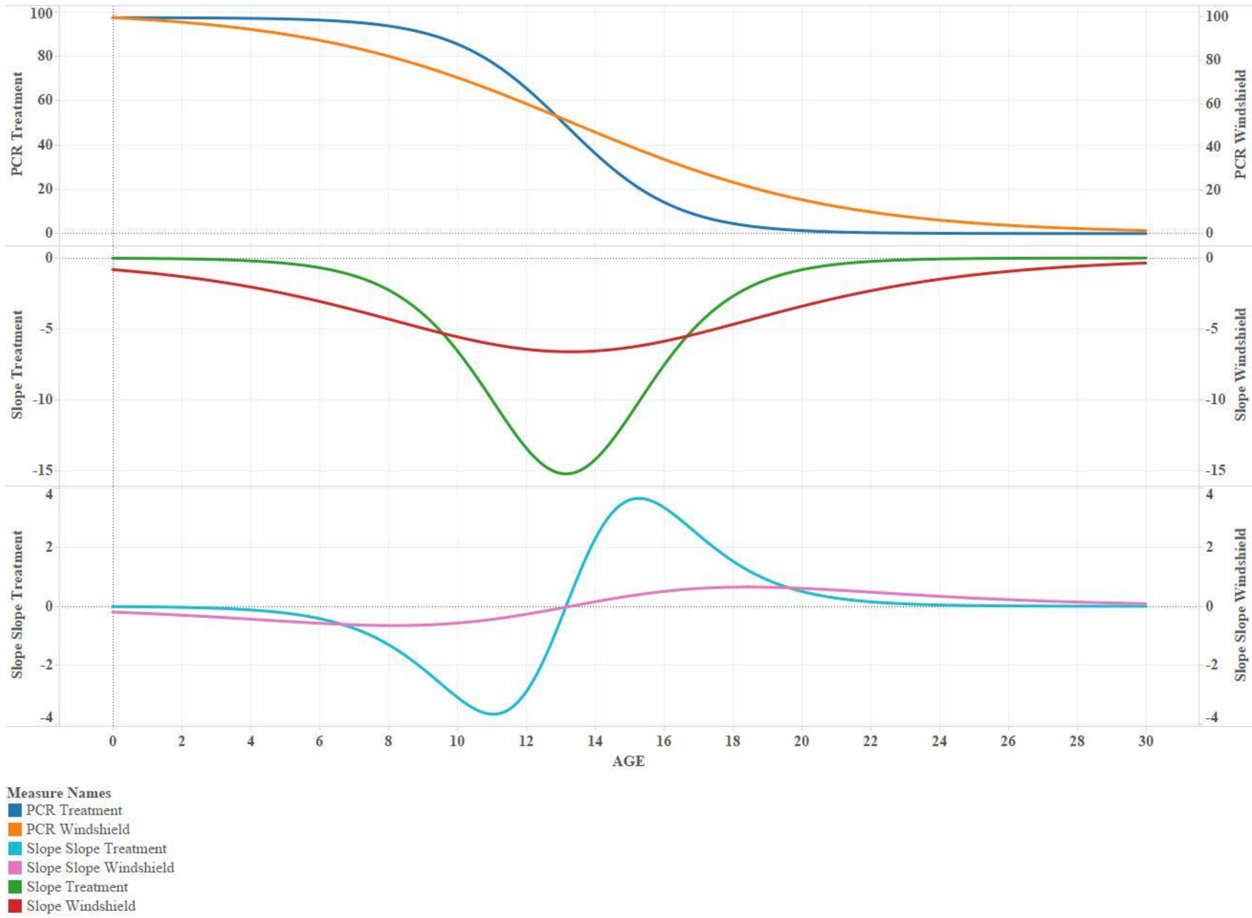


SR 15k+ (Resurface)

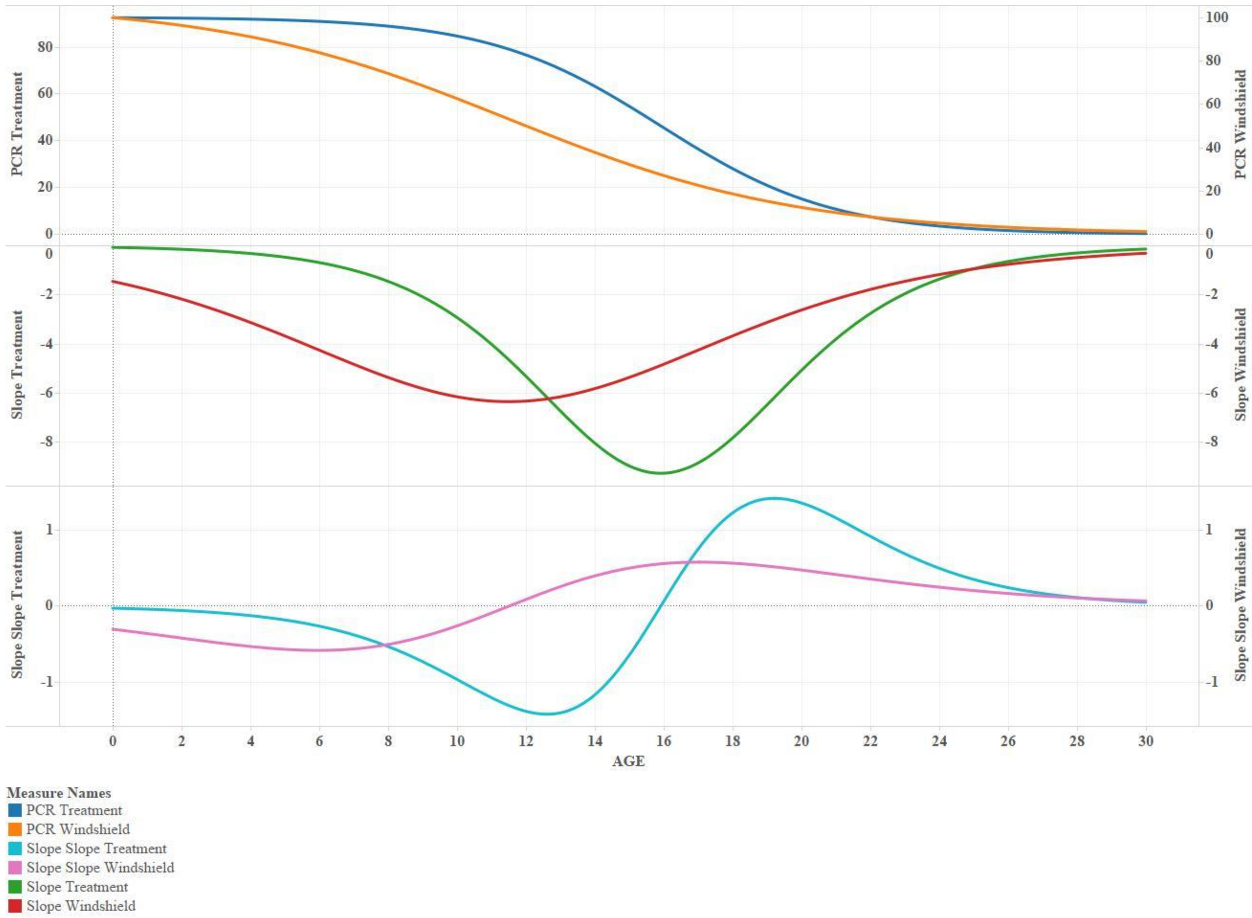
Appendix B – CBA Results

Constraint Column	Constr. Type	Scenario Year Number	Resulting Value	Cond. Threshold	Total Constraint Weight	Constraint Subdivision
Benefit	Weighted Avg	1	719.48		186717.27	
Benefit	Weighted Avg	2	667.04		186717.27	
Benefit	Weighted Avg	3	597.99		186717.27	
Benefit	Weighted Avg	4	572.39		186717.27	
Benefit	Weighted Avg	5	545.05		186717.27	
NCDOT Rating Number	Percent Above Threshold	1	.98	80.00	186717.27	
NCDOT Rating Number	Percent Above Threshold	2	1.	80.00	186717.27	
NCDOT Rating Number	Percent Above Threshold	3	.98	80.00	186717.27	
NCDOT Rating Number	Percent Above Threshold	4	.97	80.00	186717.27	
NCDOT Rating Number	Percent Above Threshold	5	.98	80.00	186717.27	
Treatment Cost	Total	1	748580030.		39518.96	Chip Seal
Treatment Cost	Total	2	4898599.		338.99	Chip Seal
Treatment Cost	Total	3	550462.		42.25	Chip Seal
Treatment Cost	Total	4	51018269.		3414.24	Chip Seal
Treatment Cost	Total	5	32231634.		2364.86	Chip Seal
Treatment Cost	Total	1	15935706.		146.71	Interstate Maintenance
Treatment Cost	Total	2	175721918.		1118.17	Interstate Maintenance
Treatment Cost	Total	3	7573341.		53.50	Interstate Maintenance
Treatment Cost	Total	4	19971881.		133.81	Interstate Maintenance
Treatment Cost	Total	5	15564247.		86.75	Interstate Maintenance
Treatment Cost	Total	1			0.00	Interstate Preservation
Treatment Cost	Total	2	17891703.		413.00	Interstate Preservation
Treatment Cost	Total	3	9072699.		206.09	Interstate Preservation
Treatment Cost	Total	4	11205924.		255.48	Interstate Preservation
Treatment Cost	Total	5	14054792.		332.74	Interstate Preservation
Treatment Cost	Total	1			0.00	Maintenance
Treatment Cost	Total	2			0.00	Maintenance
Treatment Cost	Total	3			0.00	Maintenance
Treatment Cost	Total	4			0.00	Maintenance
Treatment Cost	Total	5			0.00	Maintenance
Treatment Cost	Total	1	152966075.		22237.68	Other Preservation
Treatment Cost	Total	2	113395920.		12988.40	Other Preservation
Treatment Cost	Total	3	64032653.		12807.83	Other Preservation
Treatment Cost	Total	4	132887610.		16152.04	Other Preservation
Treatment Cost	Total	5	138981070.		23208.63	Other Preservation
Treatment Cost	Total	1	25734627.		119.25	Reconstruction
Treatment Cost	Total	2	88568870.		251.91	Reconstruction
Treatment Cost	Total	3			0.00	Reconstruction
Treatment Cost	Total	4			0.00	Reconstruction
Treatment Cost	Total	5			0.00	Reconstruction
Treatment Cost	Total	1	931964820.		8722.56	Rehabilitation
Treatment Cost	Total	2	251553188.		1510.17	Rehabilitation
Treatment Cost	Total	3	2864374.		16.85	Rehabilitation
Treatment Cost	Total	4	13700998.		106.42	Rehabilitation
Treatment Cost	Total	5	25266150.		206.70	Rehabilitation
Treatment Cost	Total	1	1689818514.		35047.92	Resurfacing
Treatment Cost	Total	2	219219731.		3477.75	Resurfacing
Treatment Cost	Total	3	3559869.		61.64	Resurfacing
Treatment Cost	Total	4	378834474.		7969.74	Resurfacing
Treatment Cost	Total	5	372904063.		7663.54	Resurfacing
Treatment Cost	Total	1			0.00	Interstates - Chip Seal
Treatment Cost	Total	2	17891703.		413.00	Interstates - Chip Seal
Treatment Cost	Total	3	9072699.		206.09	Interstates - Chip Seal
Treatment Cost	Total	4	11205924.		255.48	Interstates - Chip Seal
Treatment Cost	Total	5	14054792.		332.74	Interstates - Chip Seal

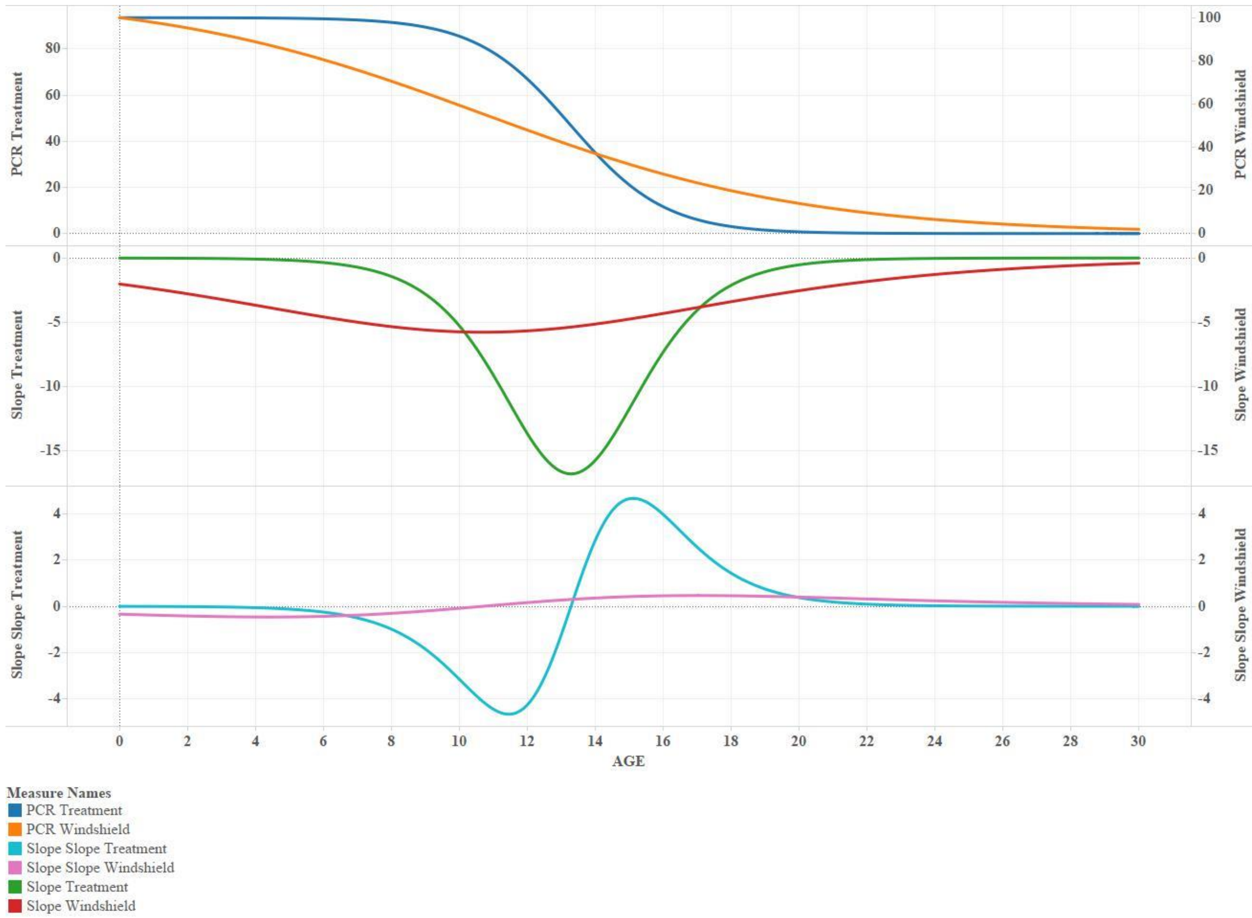
Appendix C – Comparison Figures



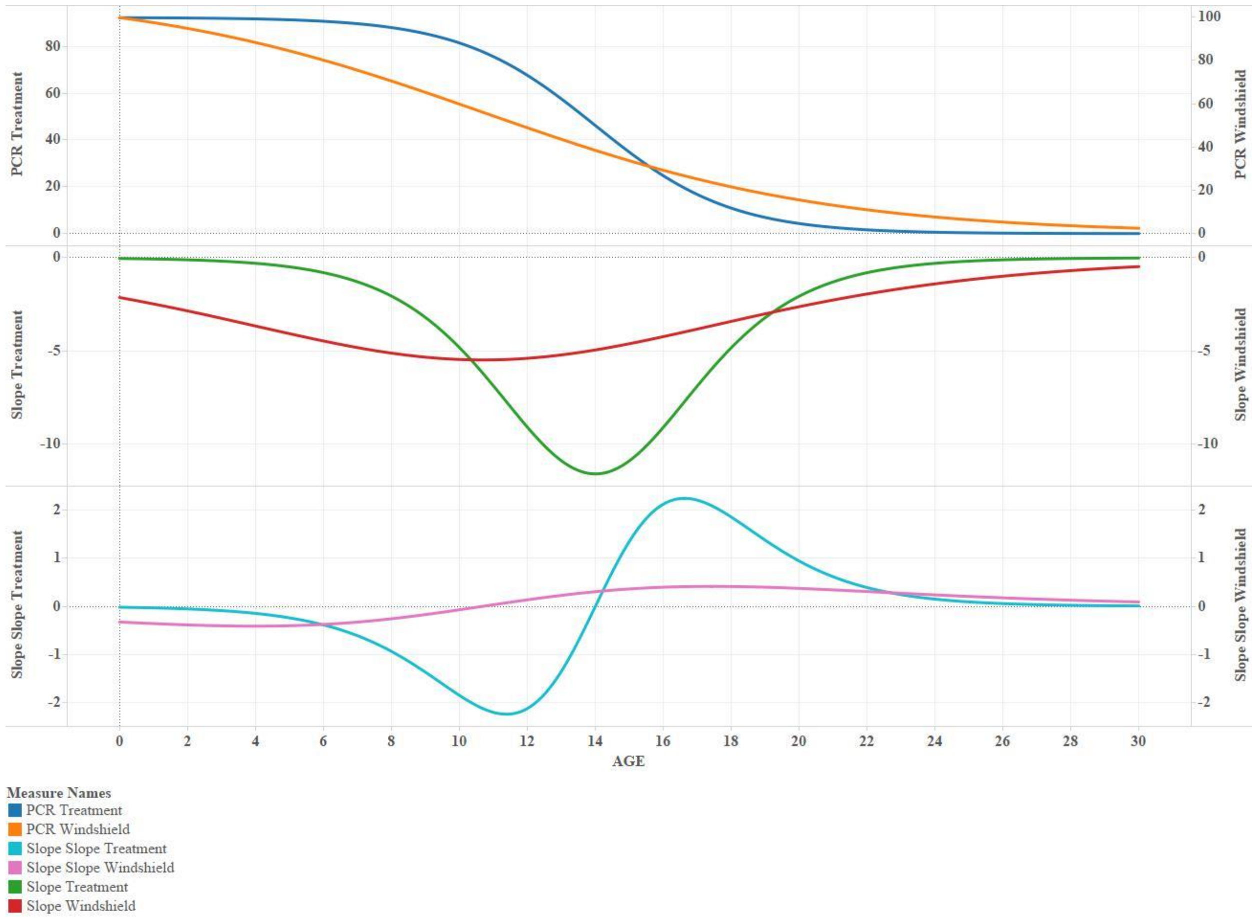
Interstate 0-50k: *AC Construction/Reconstruction* vs. Original



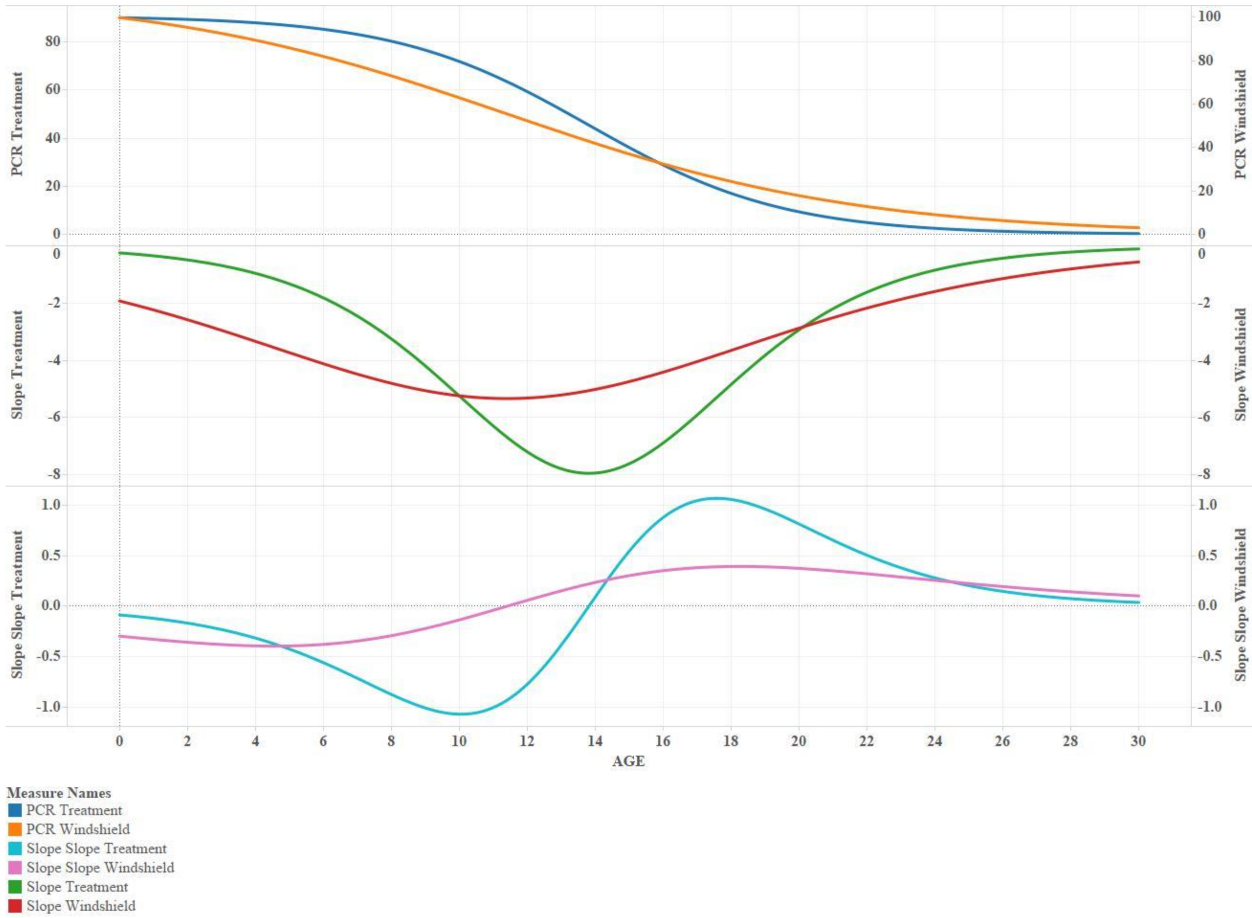
Interstate 50k+: *AC Construction/Reconstruction* vs. Original



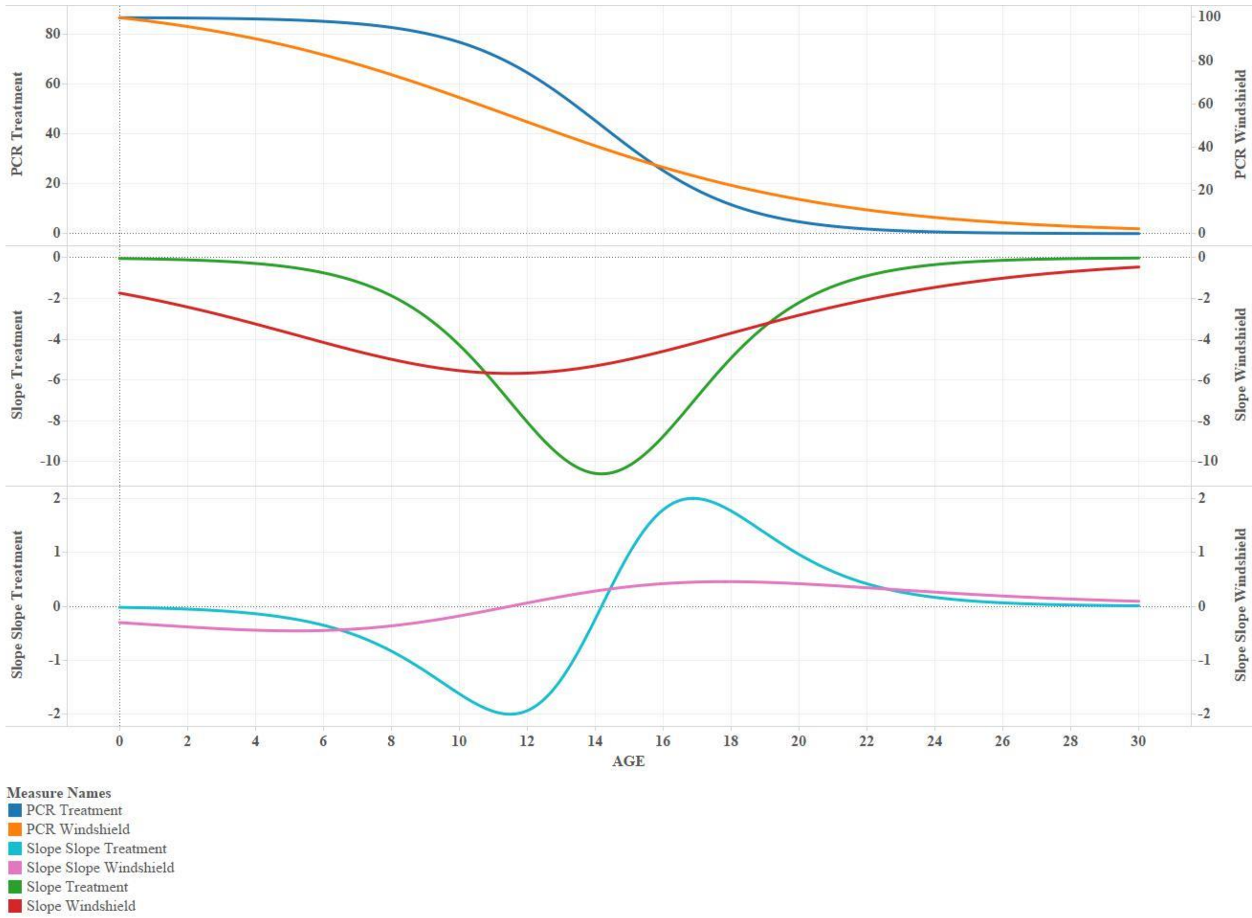
US 0-5k: *AC Construction/Reconstruction* vs. Original



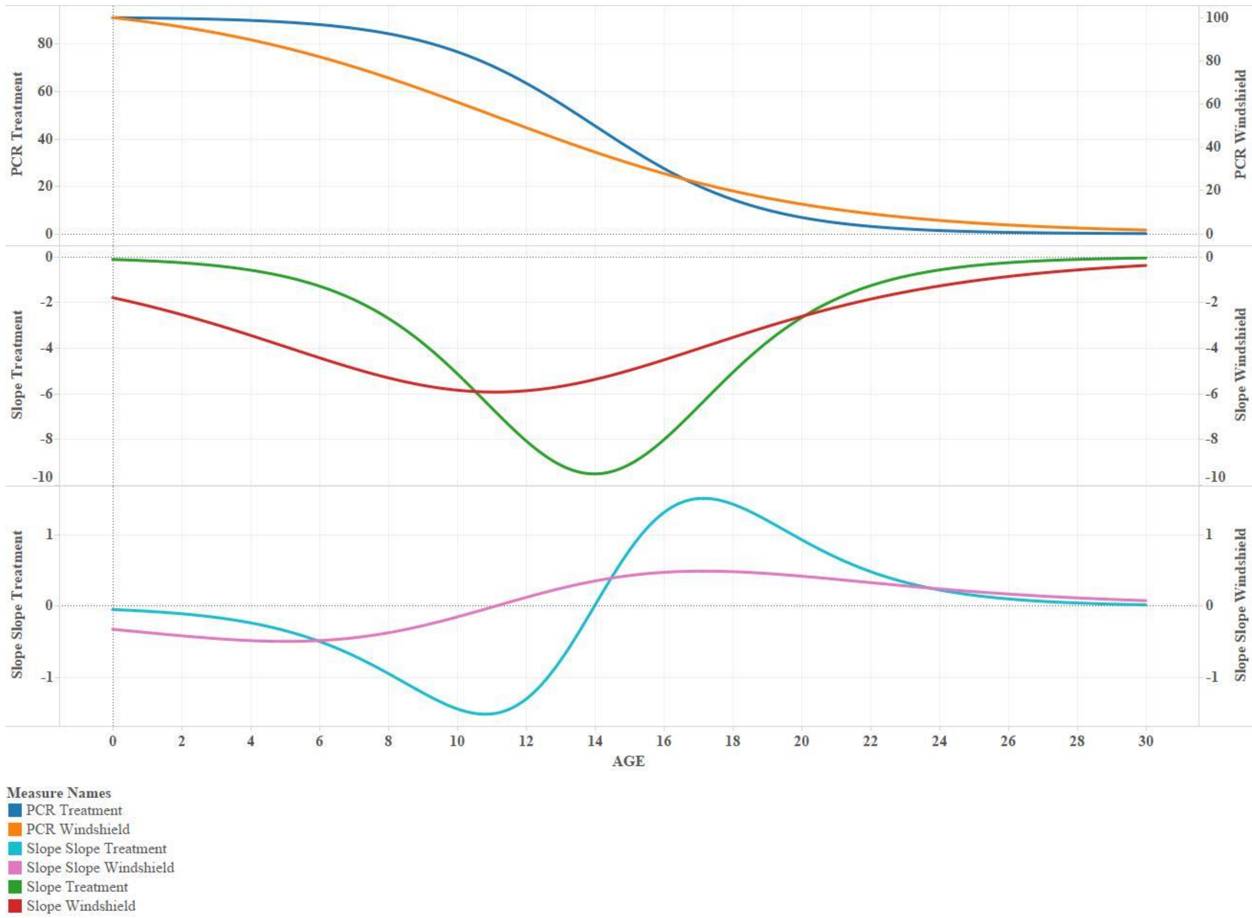
US 5-15k: *AC Construction/Reconstruction* vs. Original



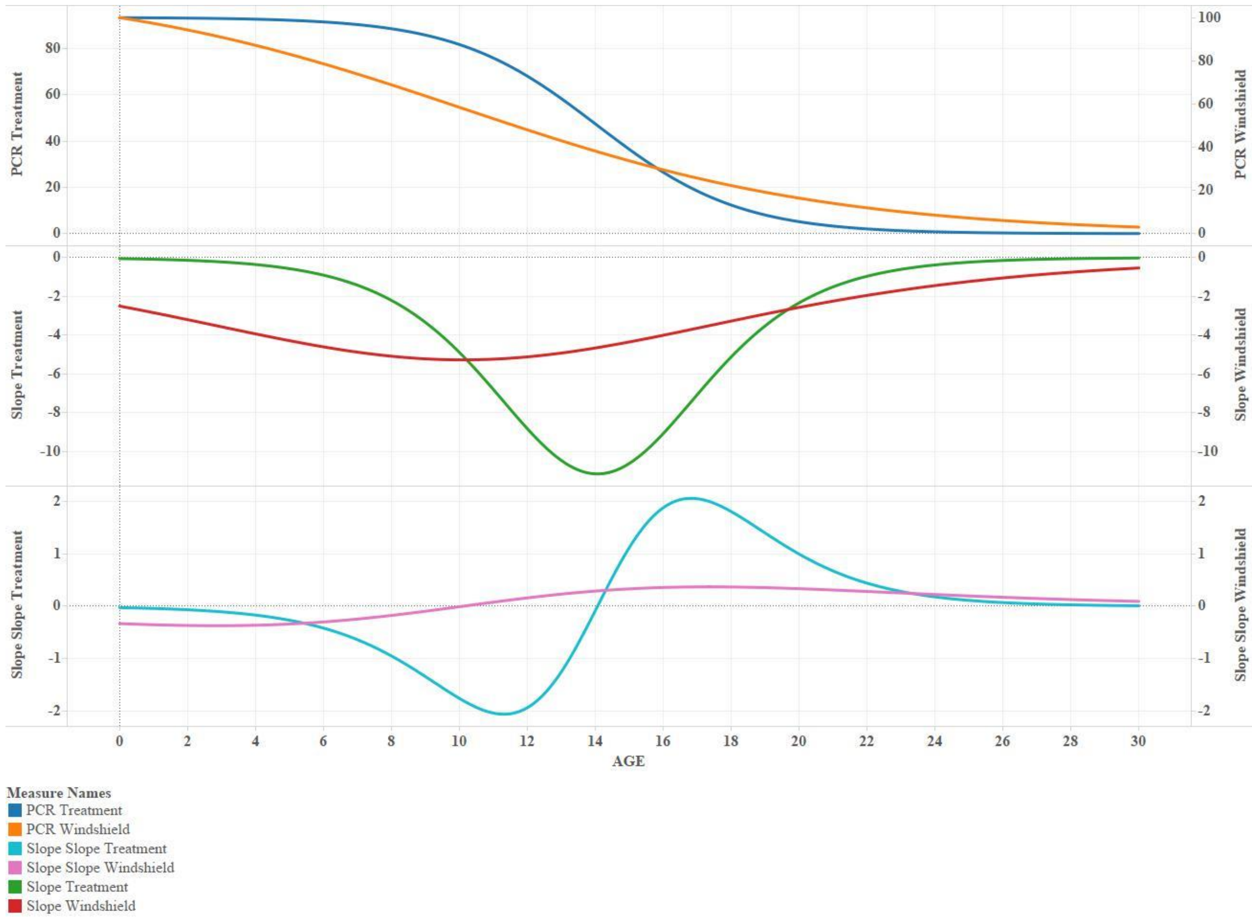
US 15-30k: *AC Construction/Reconstruction* vs. Original



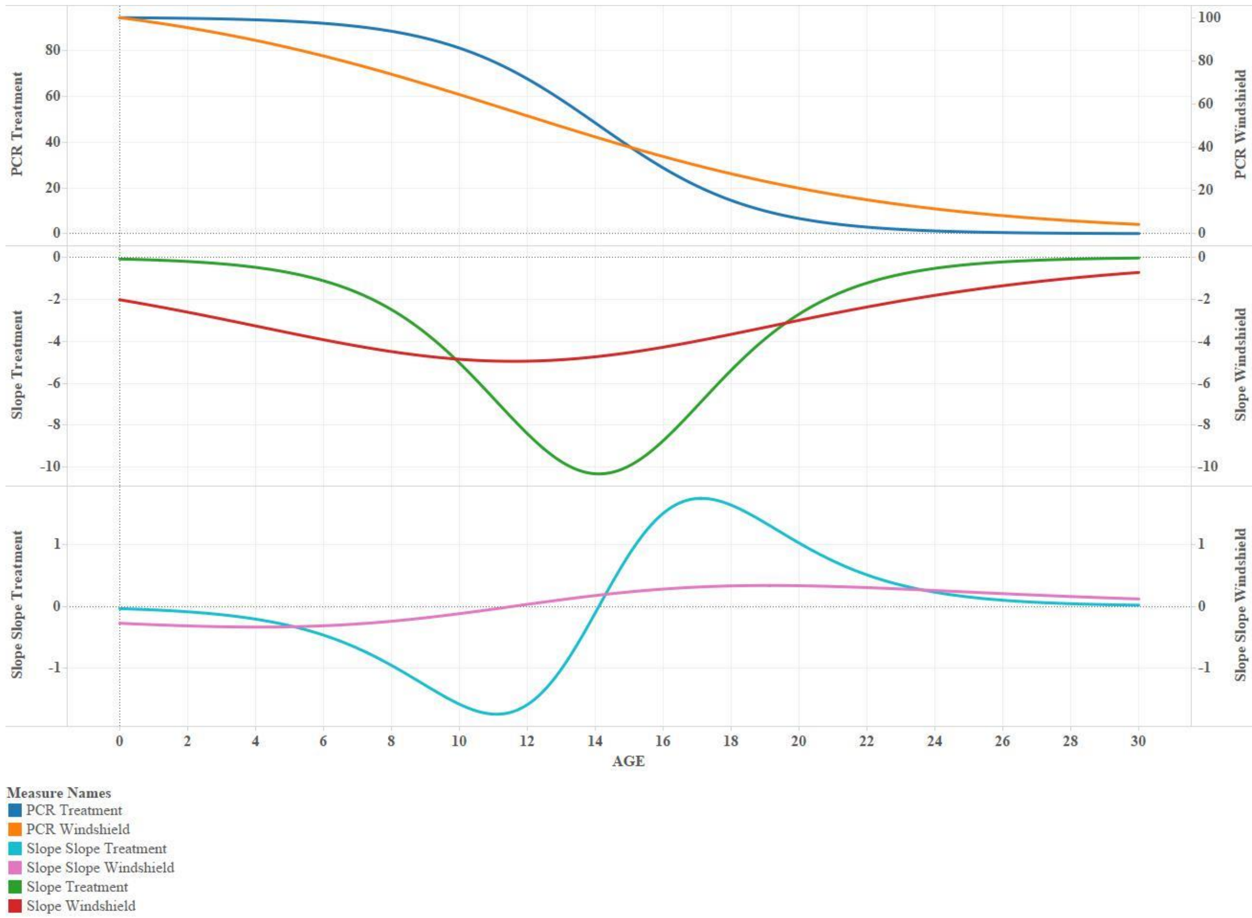
NC 0-1k: *AC Construction/Reconstruction* vs. Original



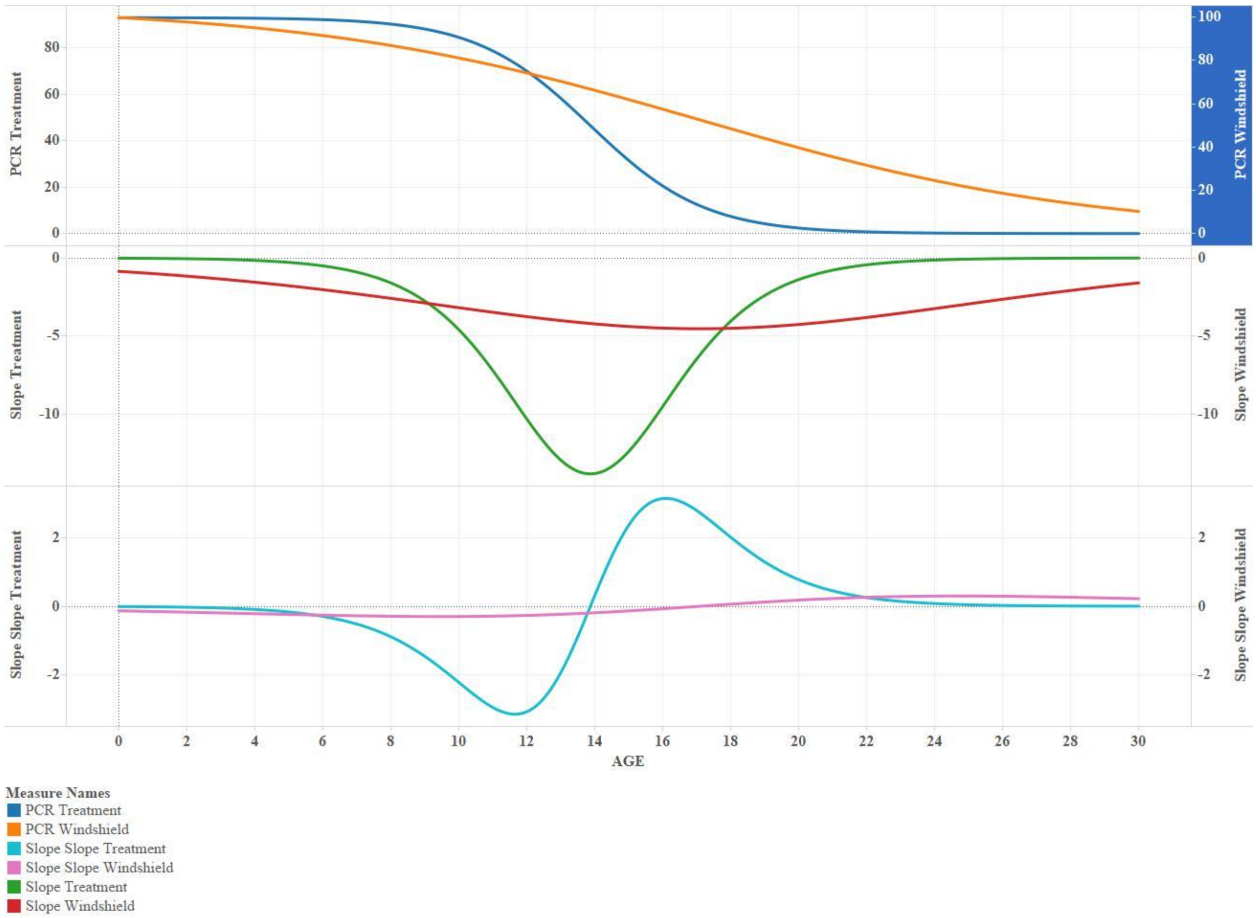
NC 1-5k: *AC Construction/Reconstruction* vs. Original



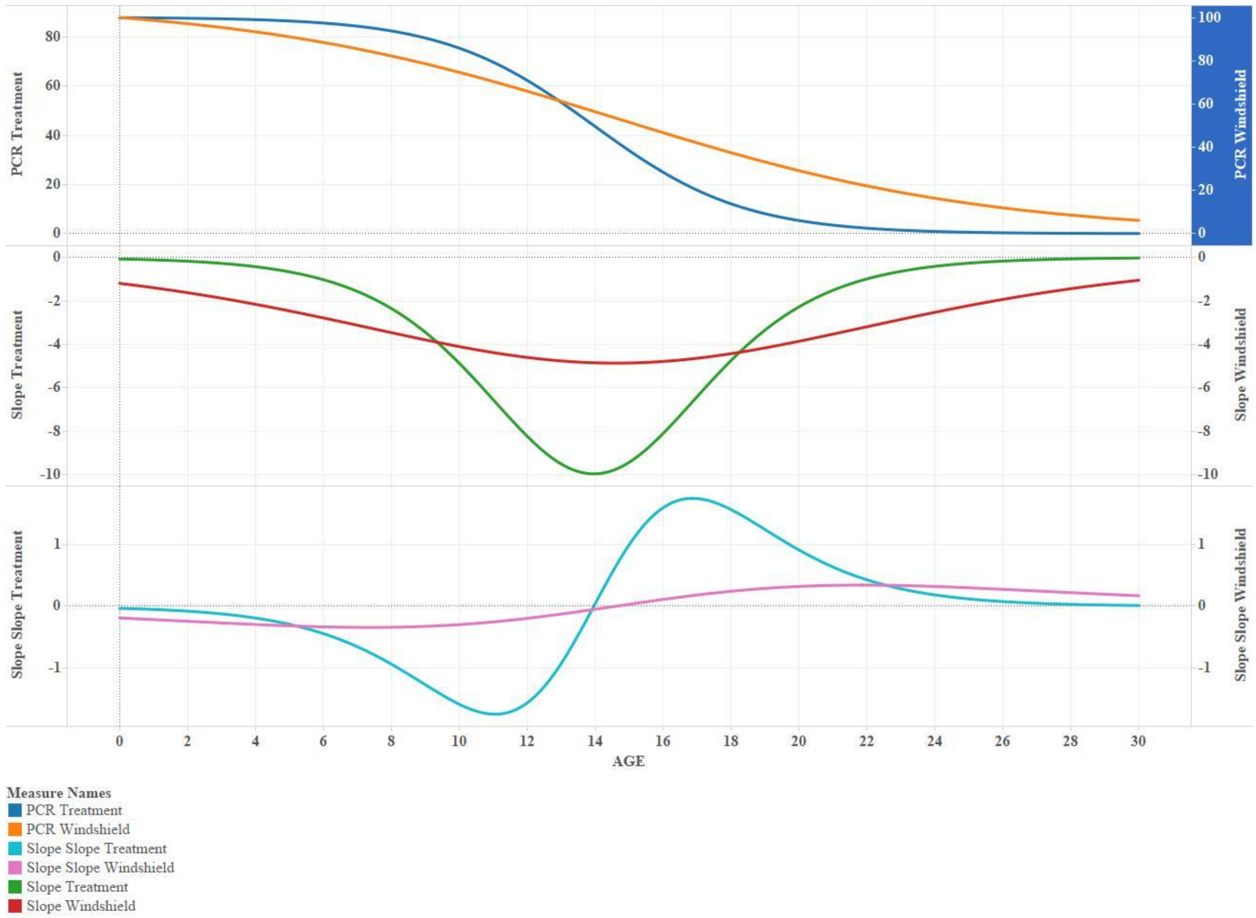
NC 5-15k: *AC Construction/Reconstruction* vs. Original



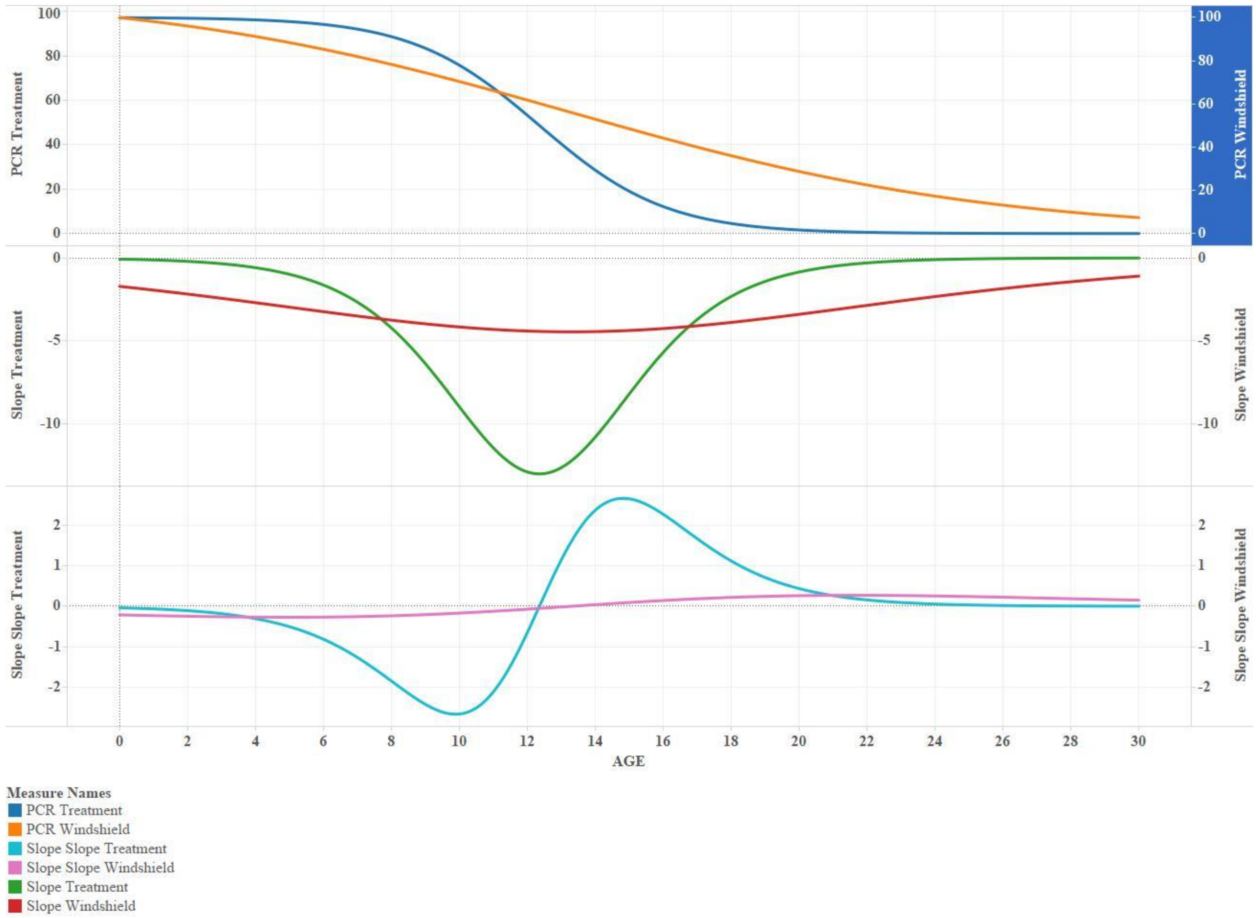
NC 15k+: *AC Construction/Reconstruction* vs. Original



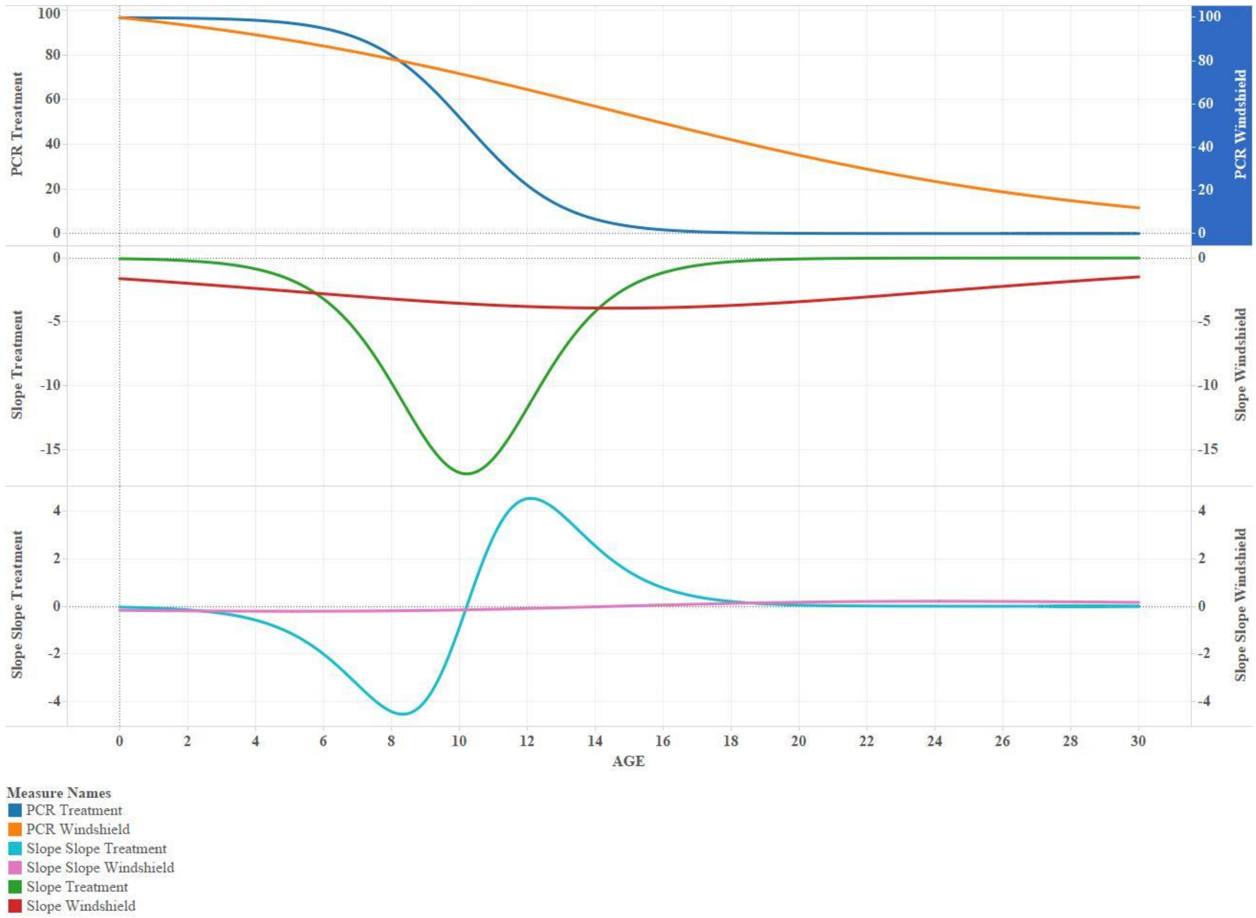
SR 0-1k: *AC Construction/Reconstruction* vs. Original



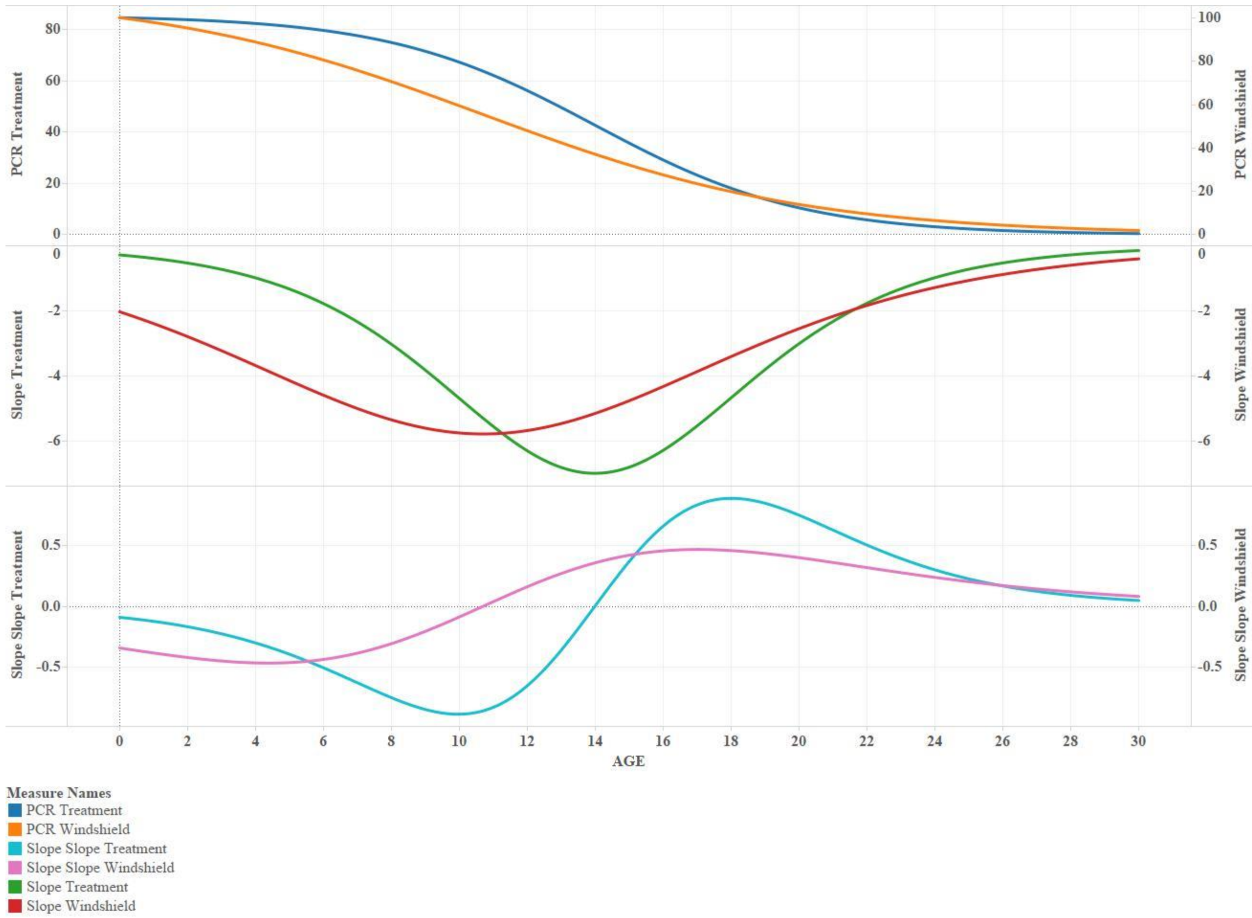
SR 1-5k: *AC Construction/Reconstruction* vs. Original



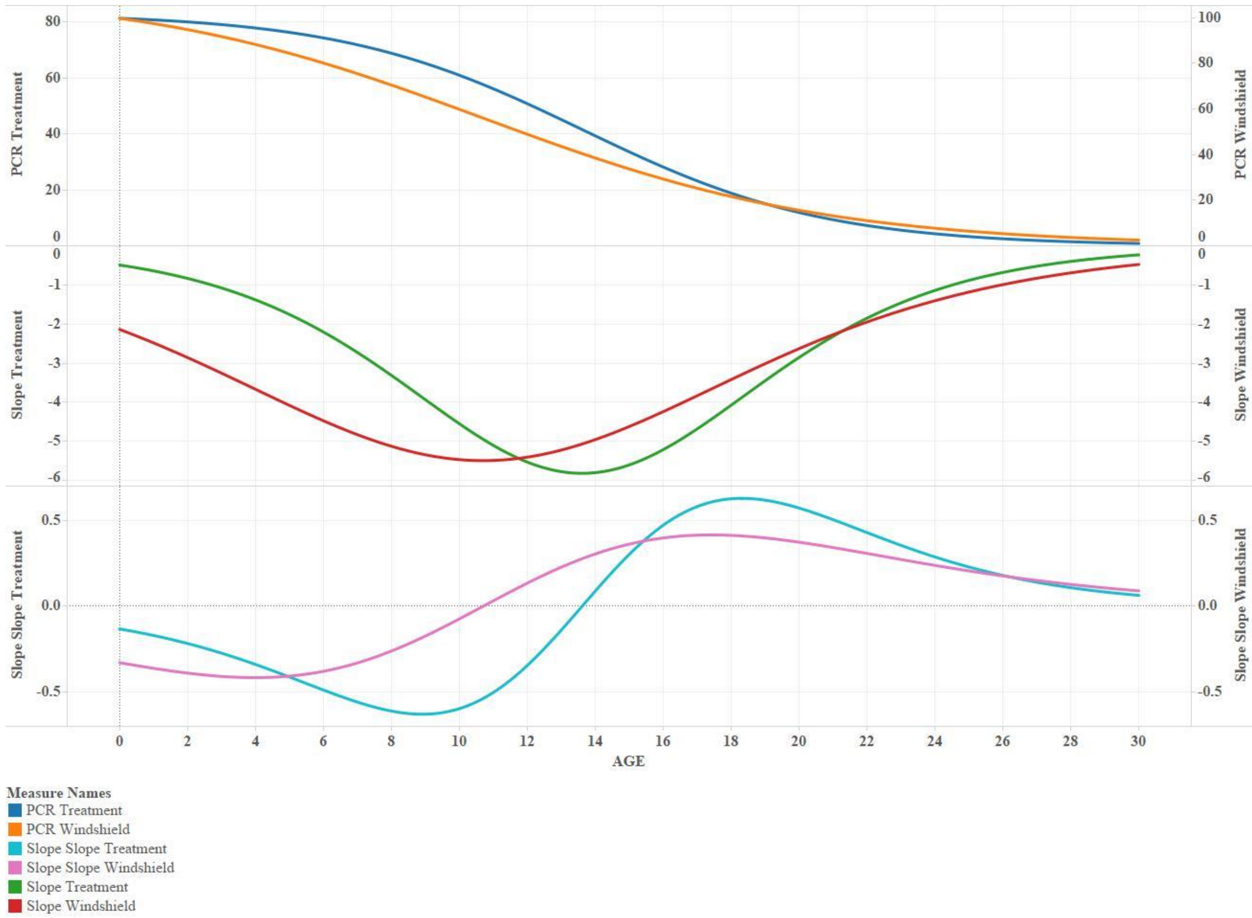
SR 5-15k: *AC Construction/Reconstruction* vs. Original



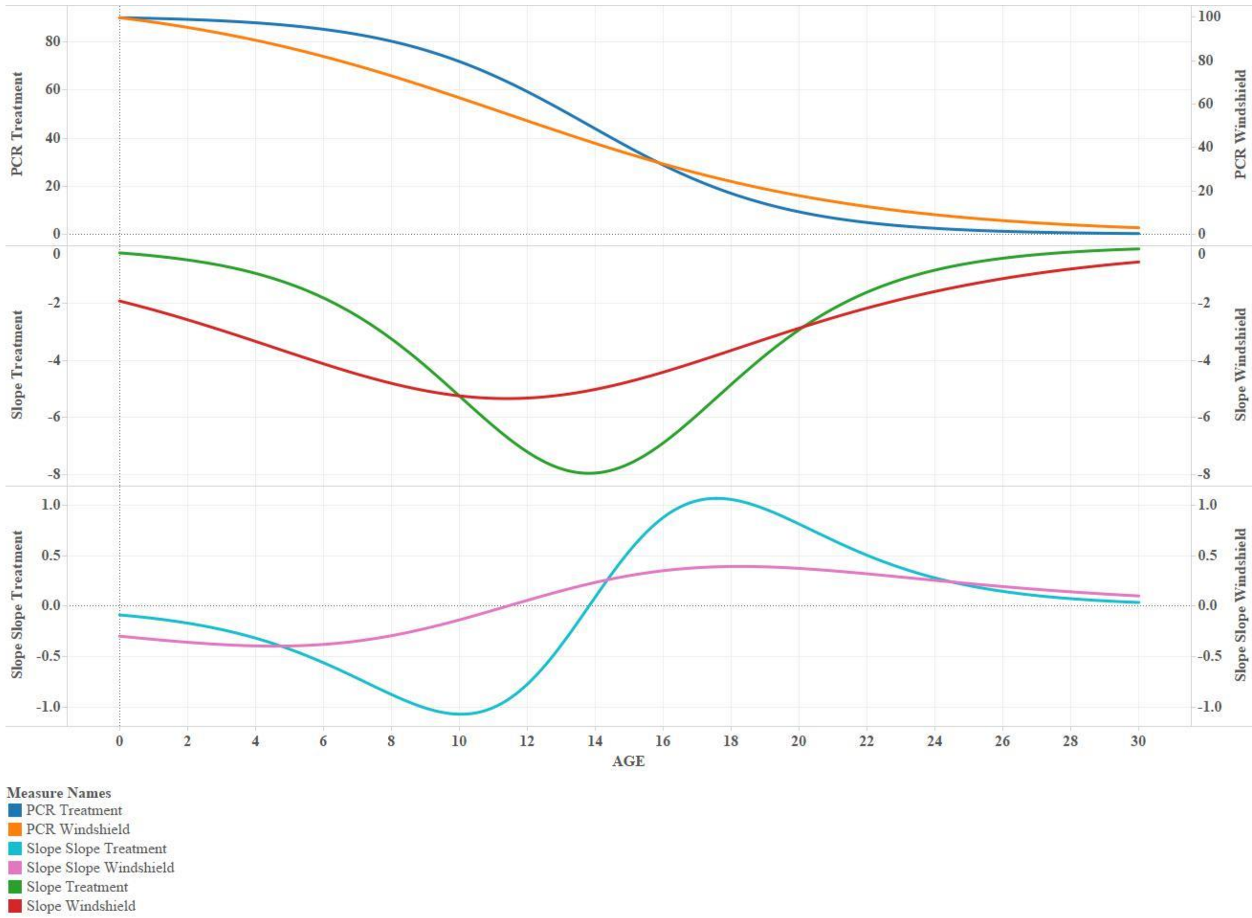
SR 15k+: *AC Construction/Reconstruction* vs. Original



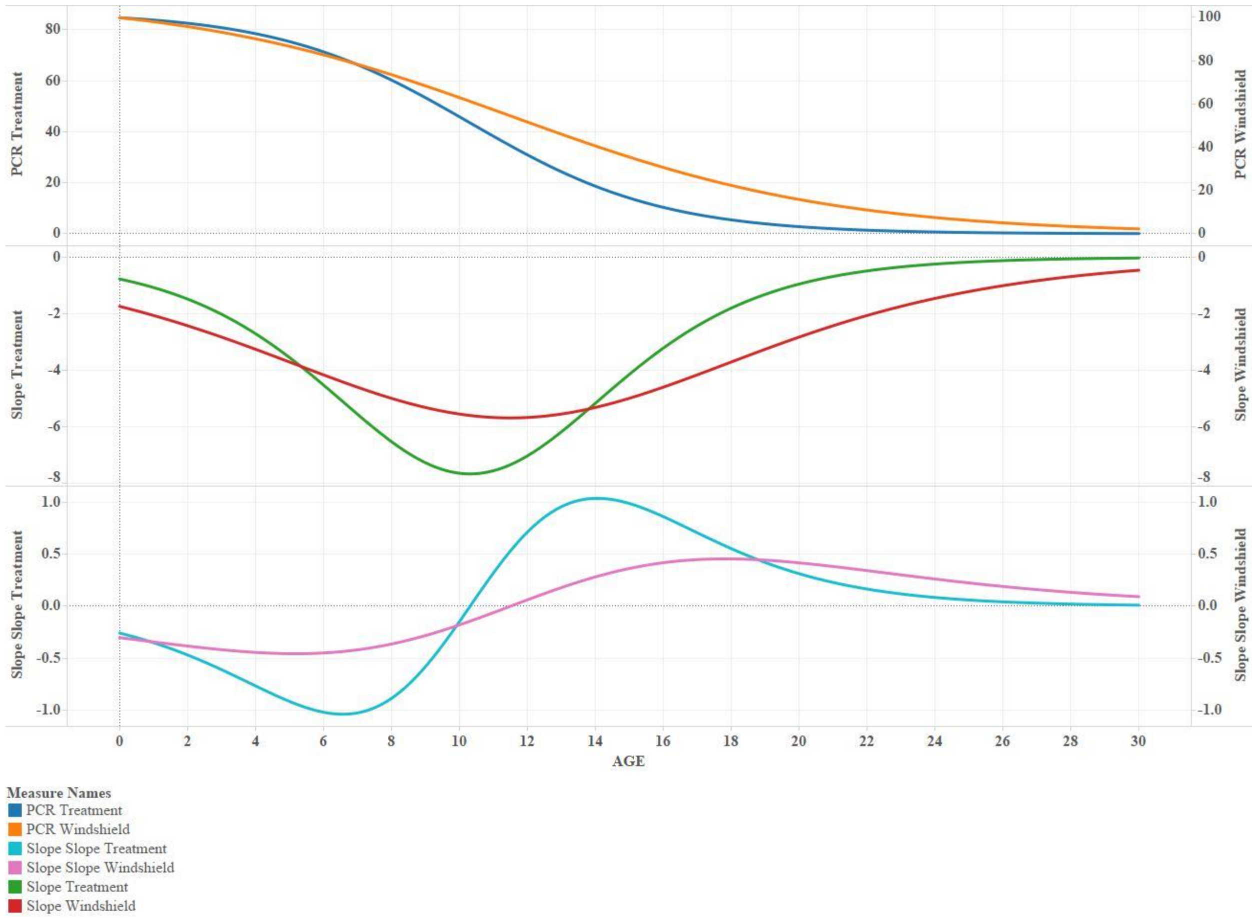
US 0-5k: *Chip Seal* vs. Original



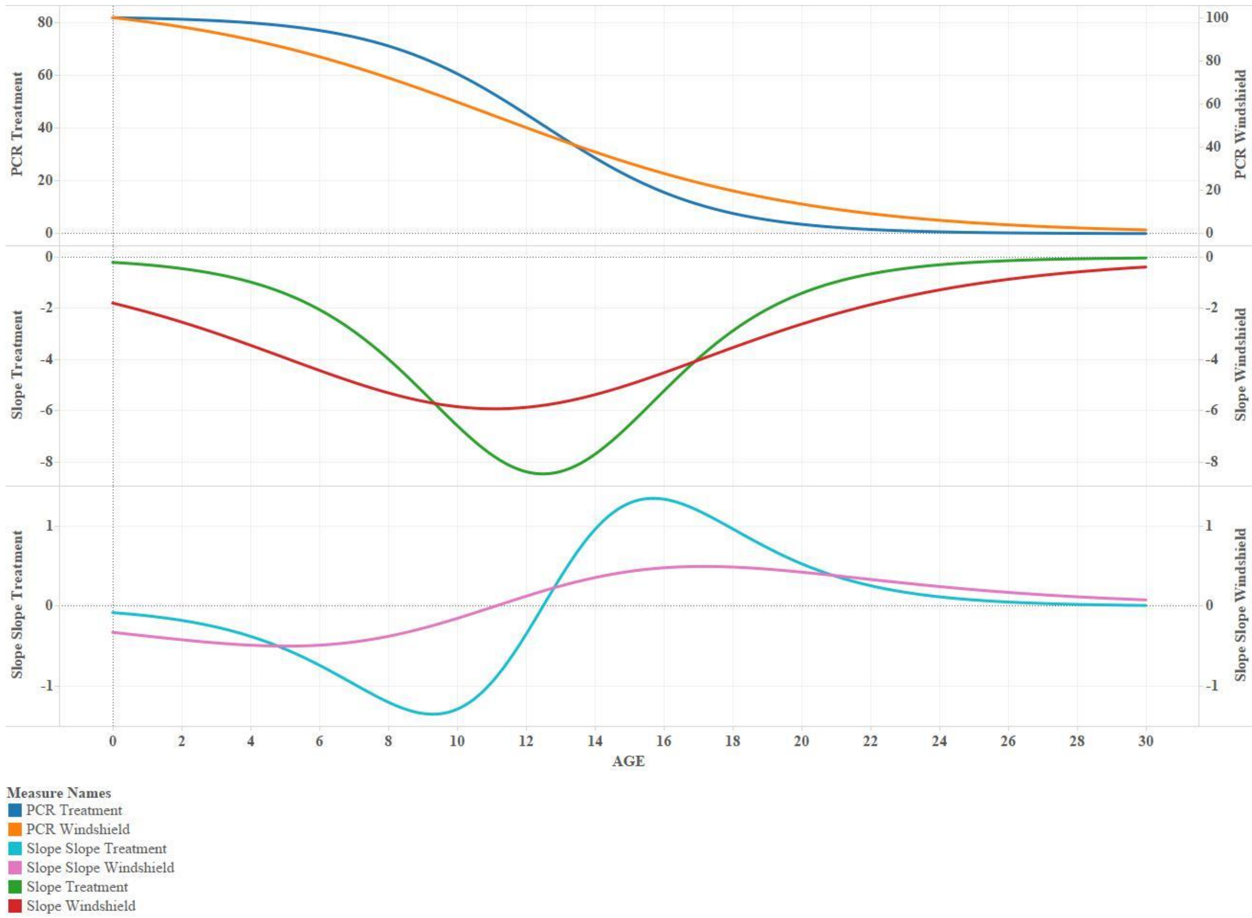
US 5-15k: *Chip Seal* vs. Original



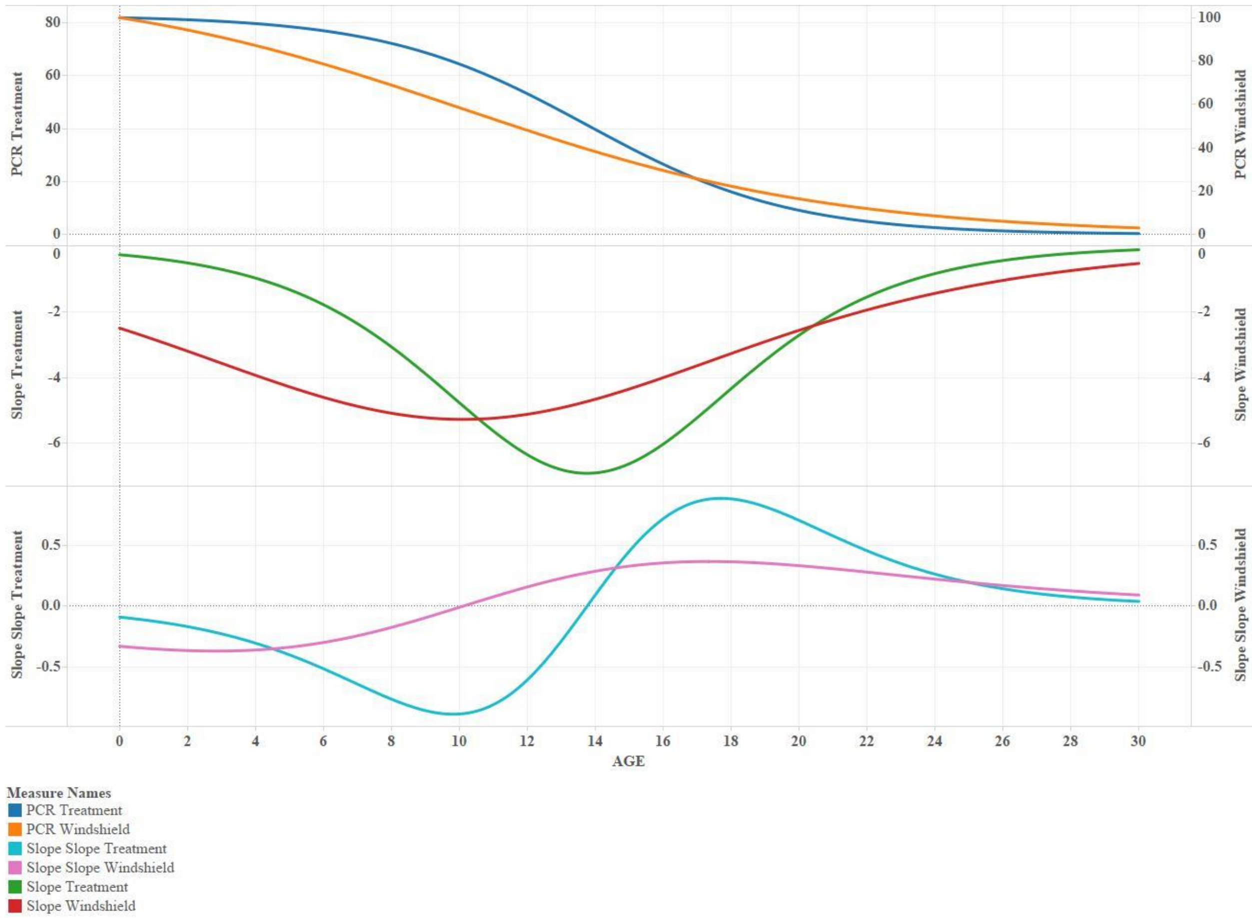
US 15-30k: *Chip Seal* vs. Original



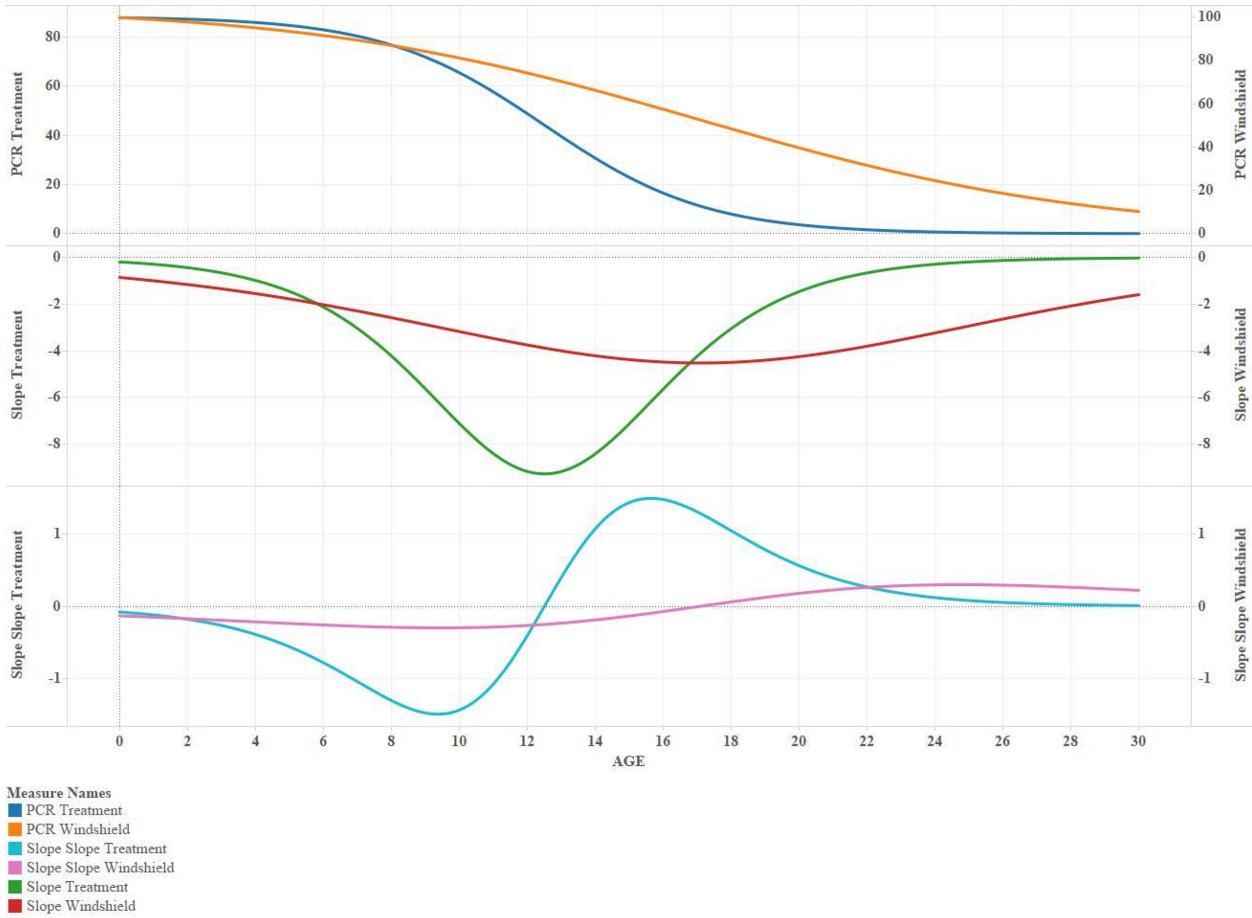
NC 0-1k: *Chip Seal* vs. Original



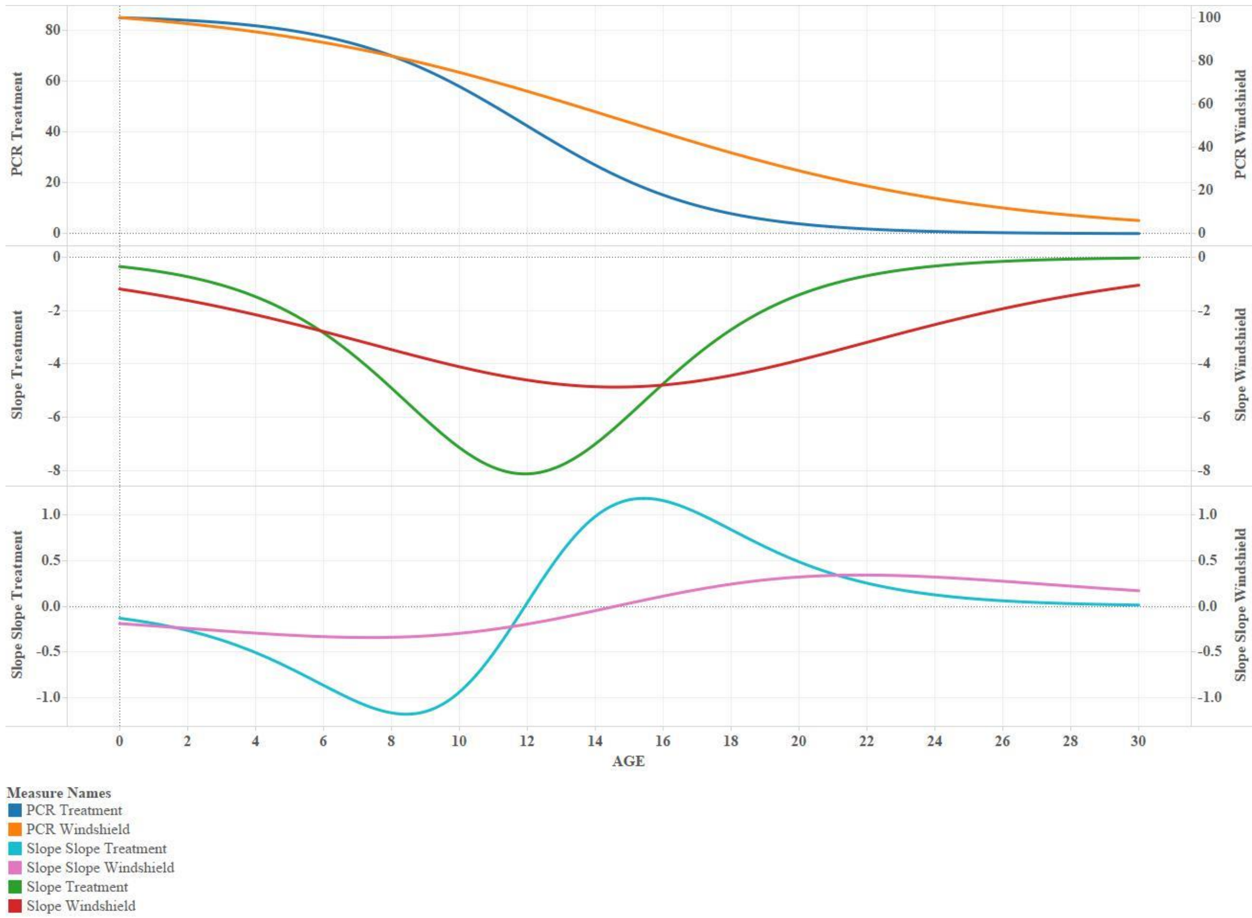
NC 1-5k: *Chip Seal* vs. Original



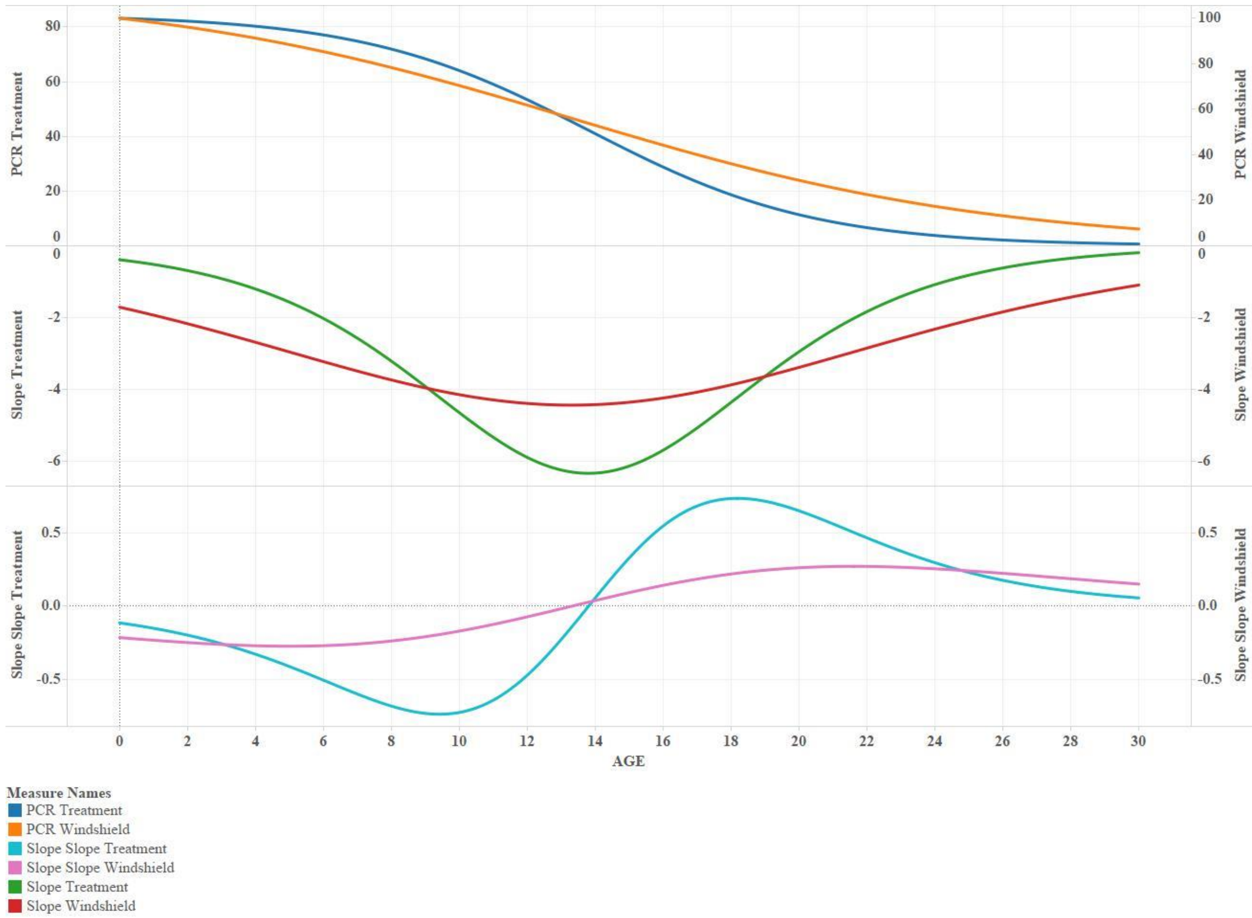
NC 5-15k: *Chip Seal* vs. Original



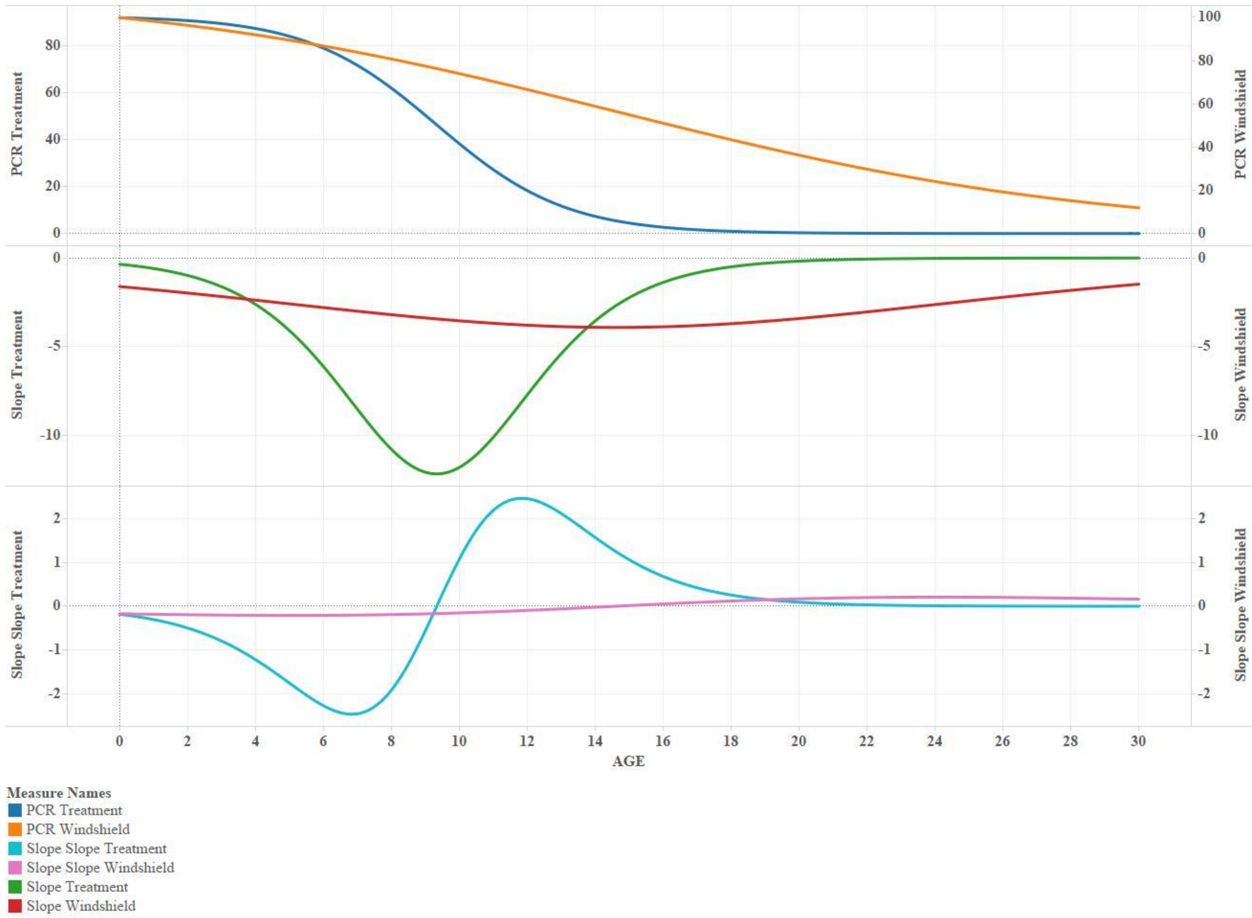
SR 0-1k: *Chip Seal* vs. Original



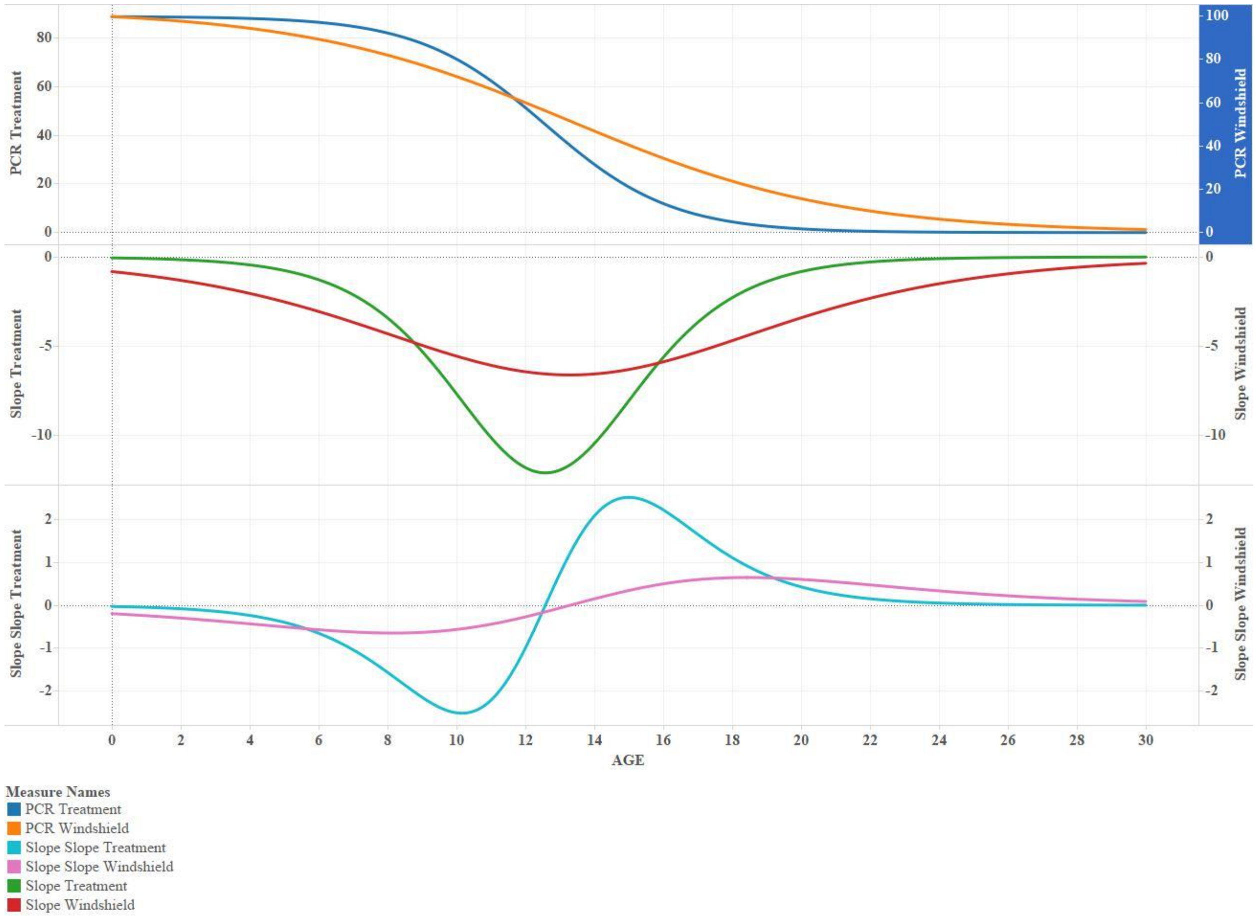
SR 1-5k: *Chip Seal* vs. Original



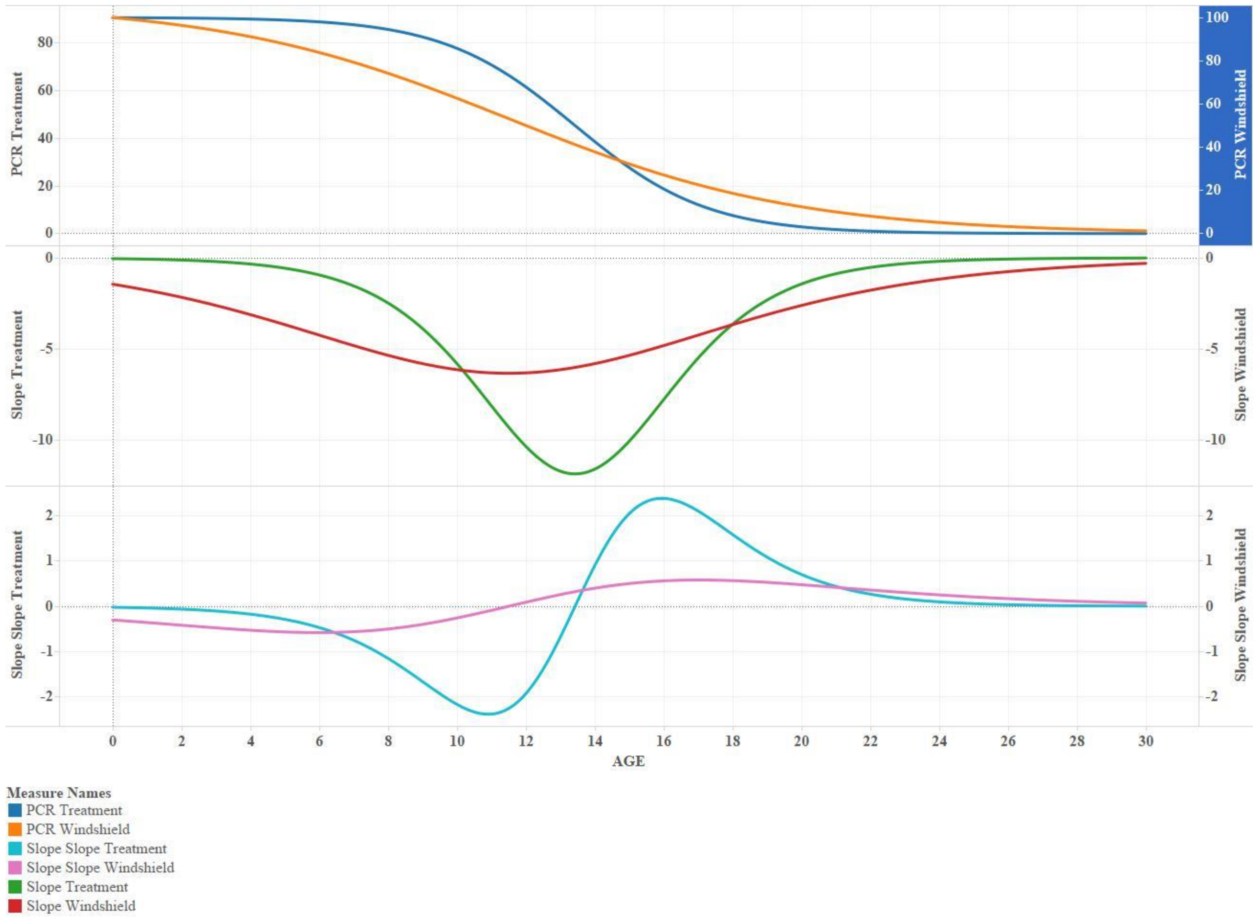
SR 5-15k: *Chip Seal* vs. Original



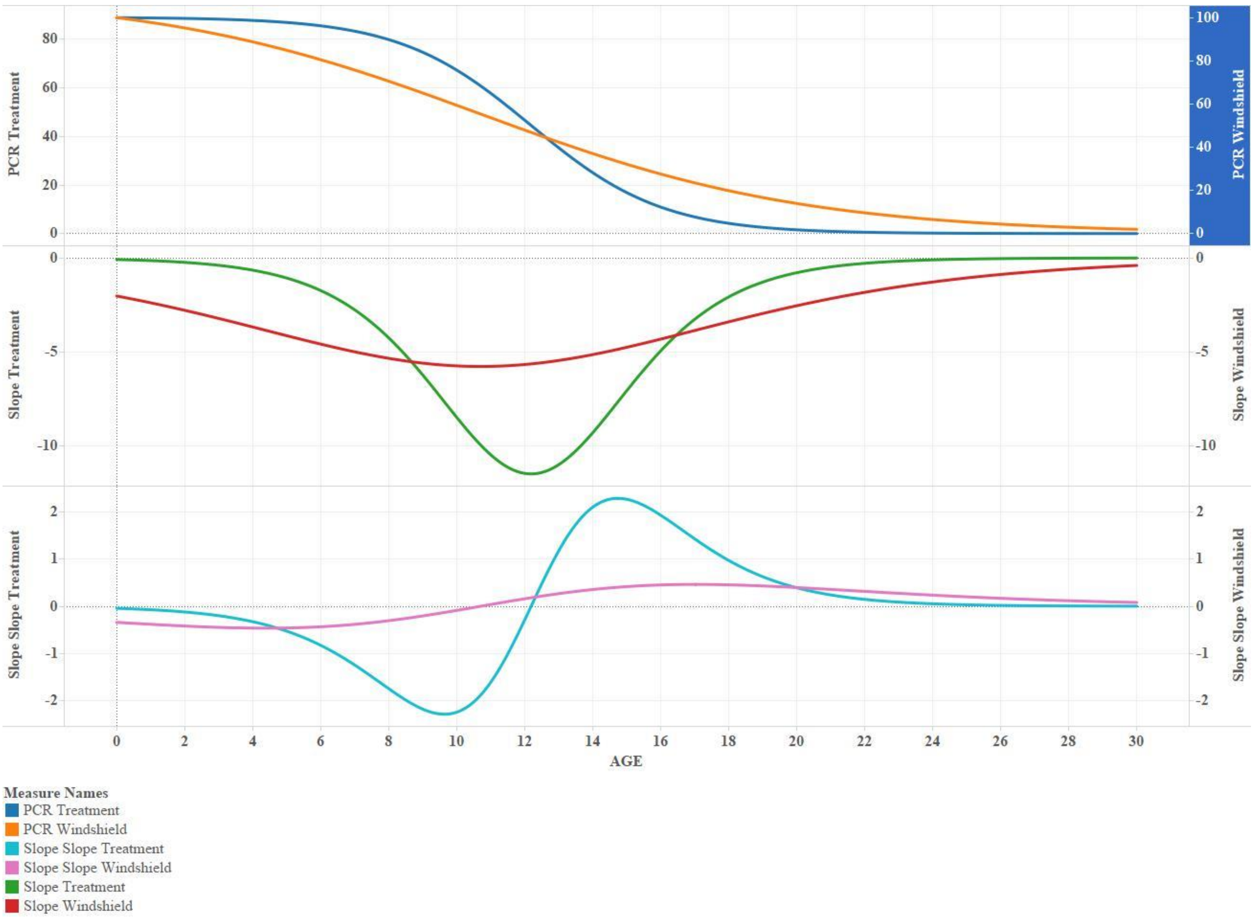
SR 15k+: *Chip Seal* vs. Original



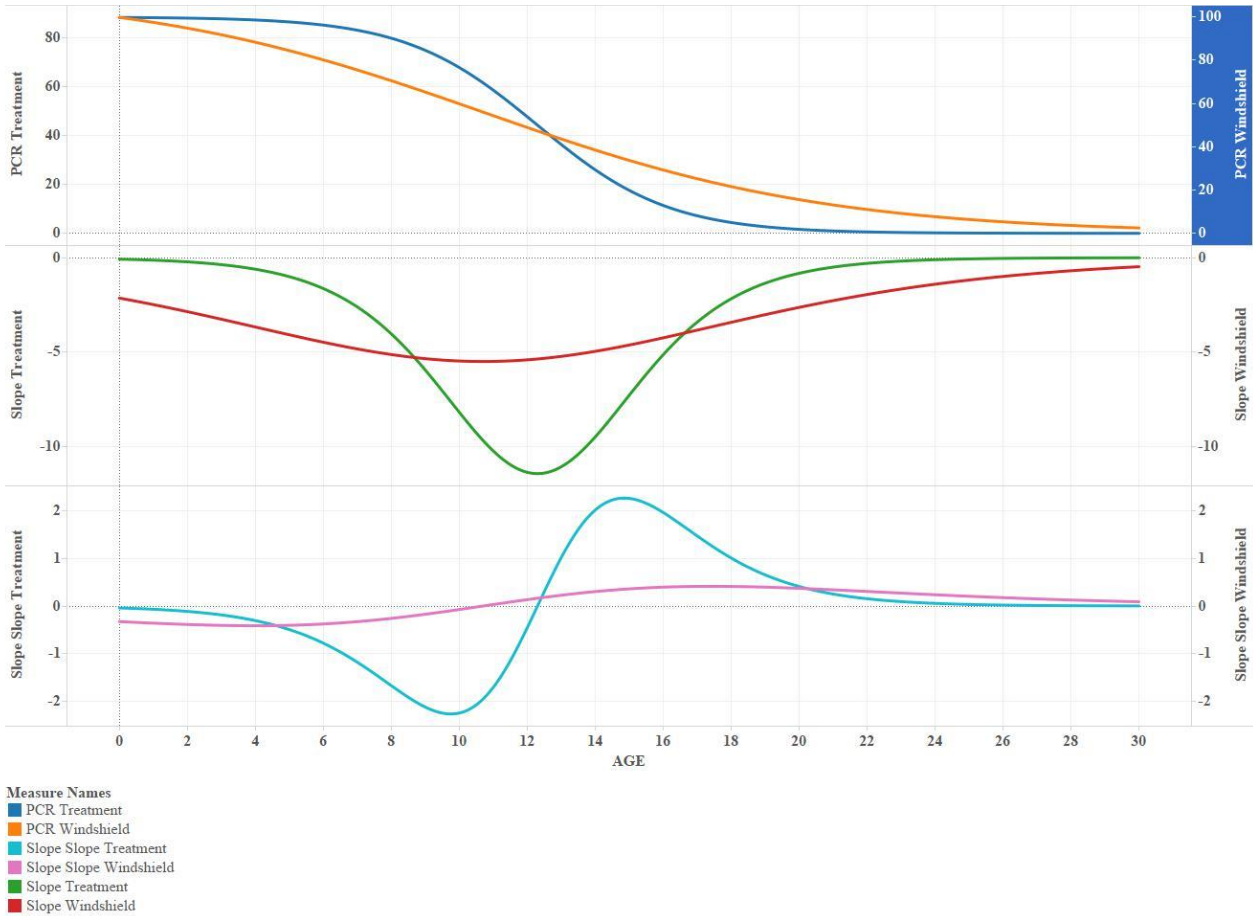
Interstate 0-50k: *Mill + Resurface* vs. Original



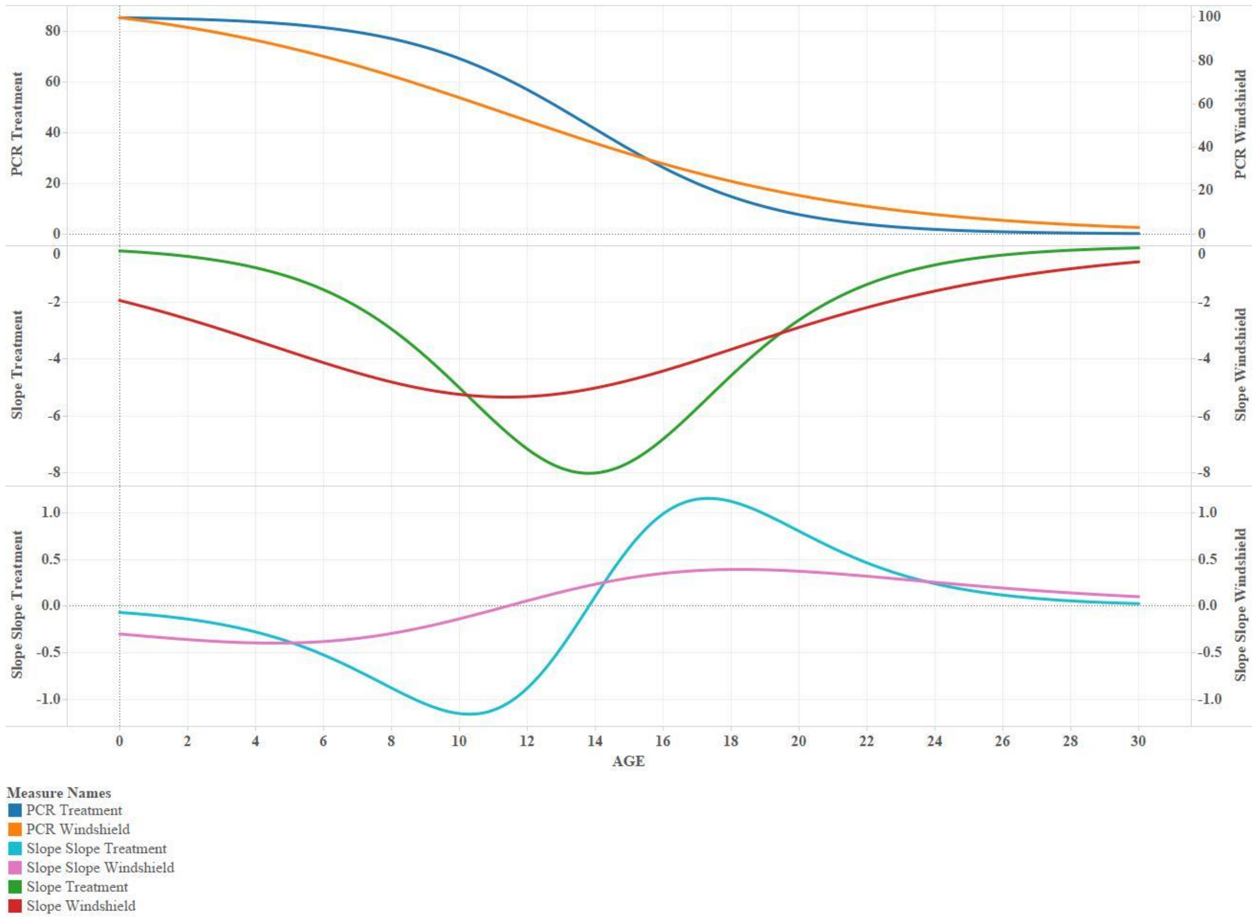
Interstate 50k+: *Mill + Resurface* vs. Original



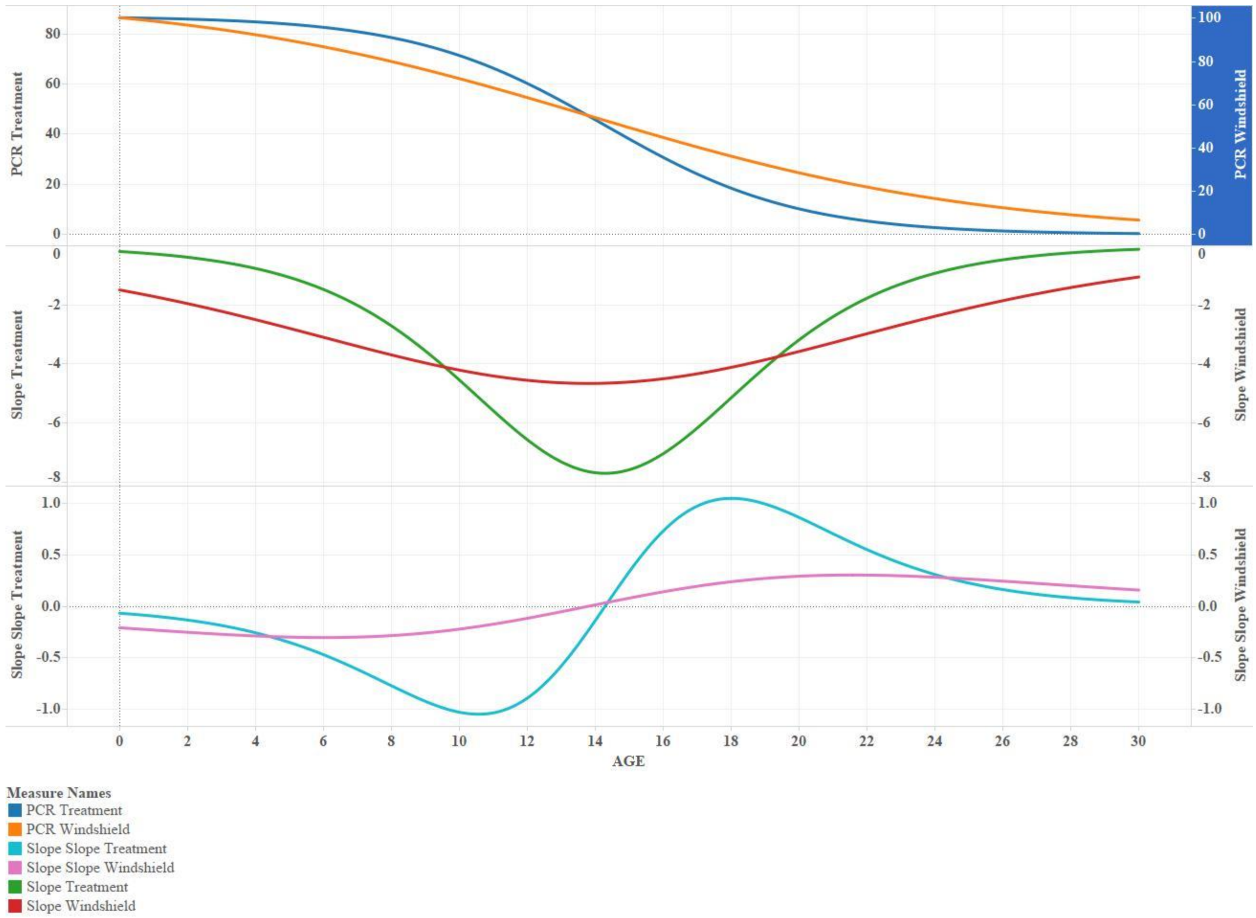
US 0-5k: *Mill + Resurface* vs. Original



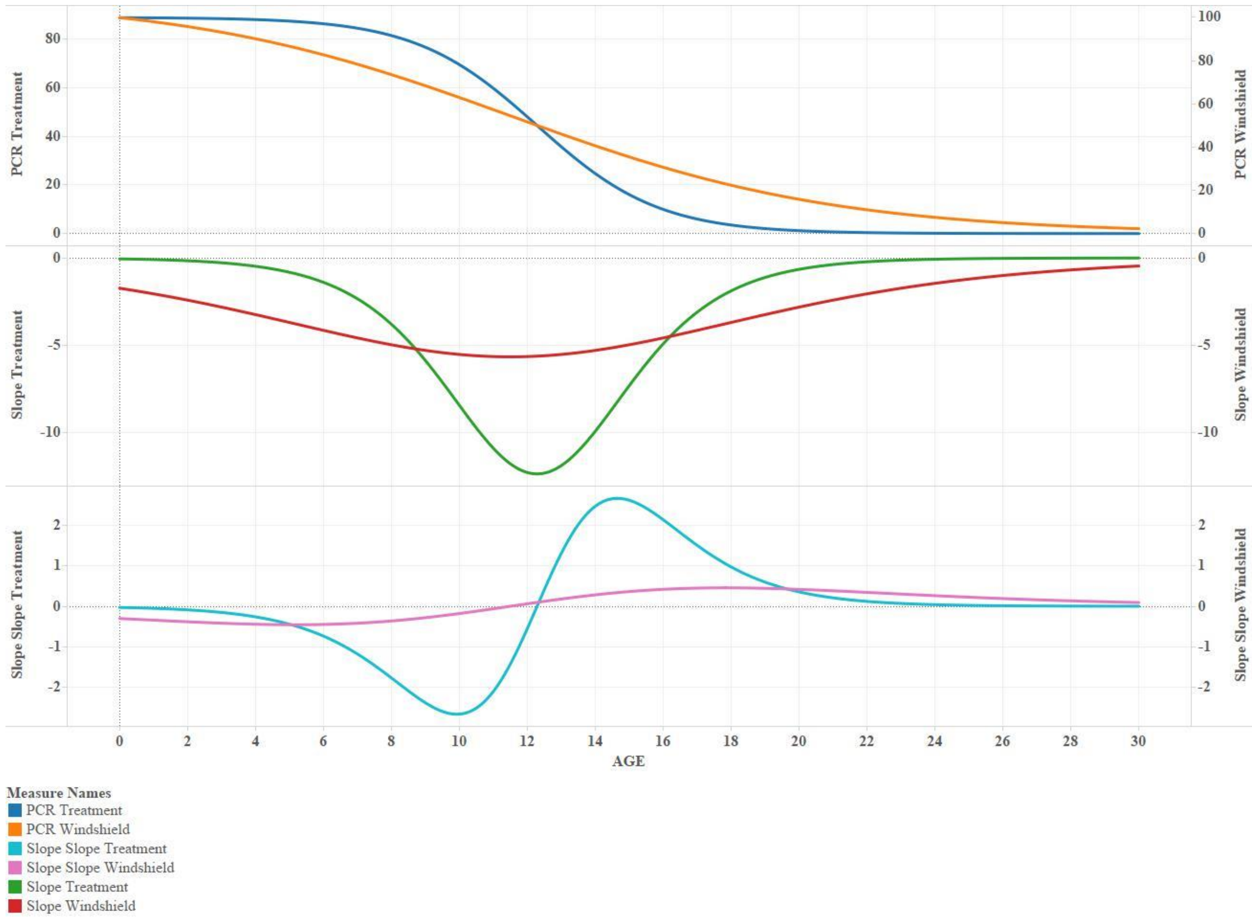
US 5-15k: *Mill + Resurface* vs. Original



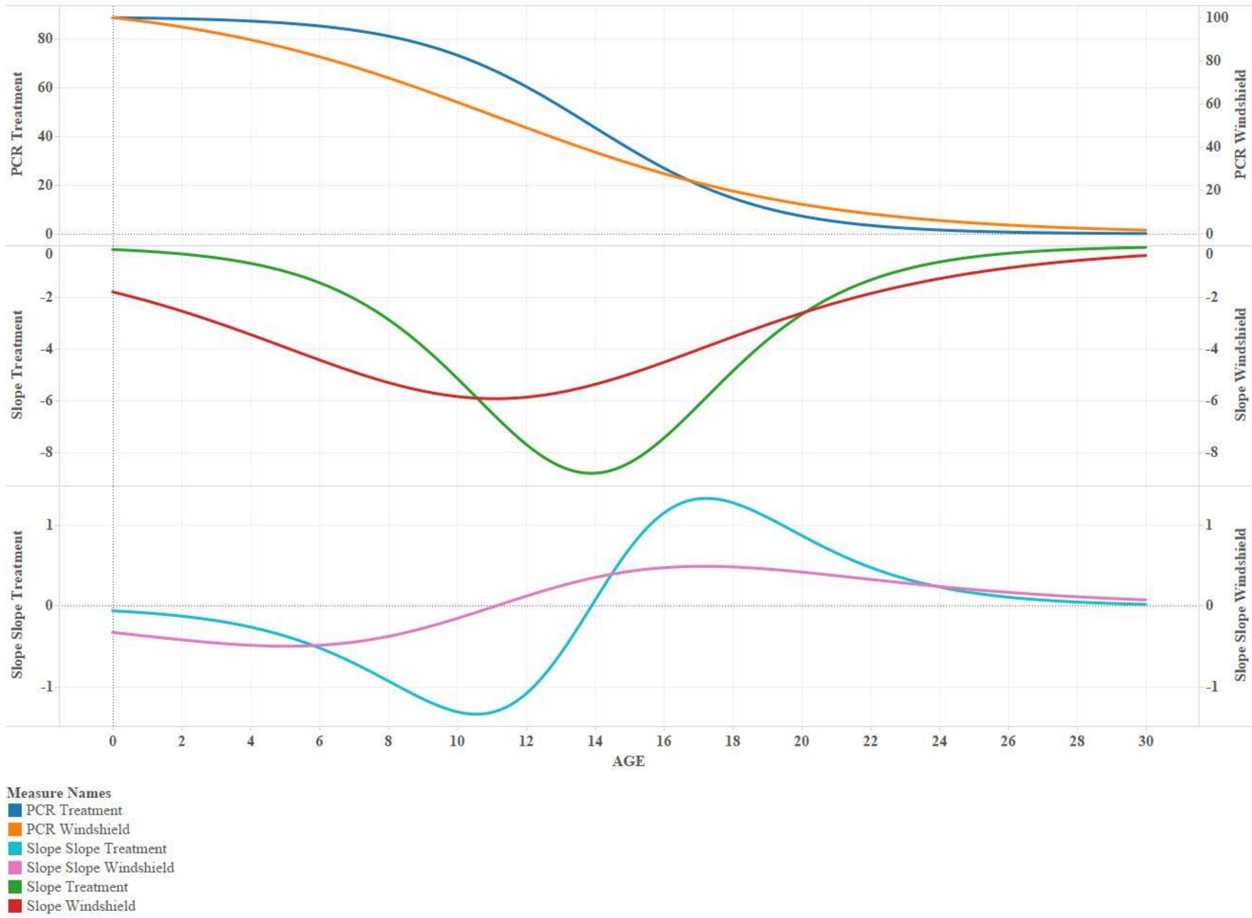
US 15-30k: *Mill + Resurface* vs. Original



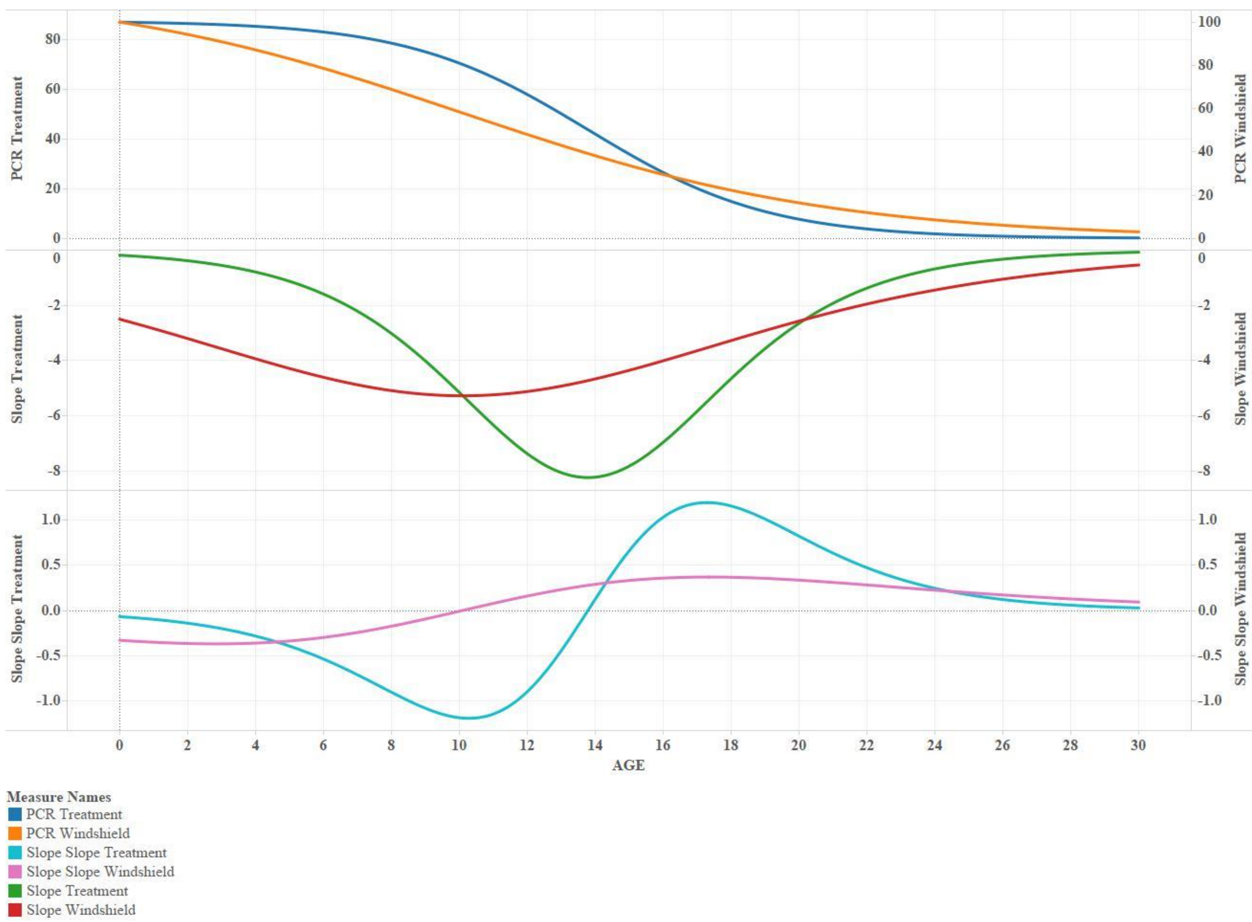
US 30k+: *Mill + Resurface* vs. Original



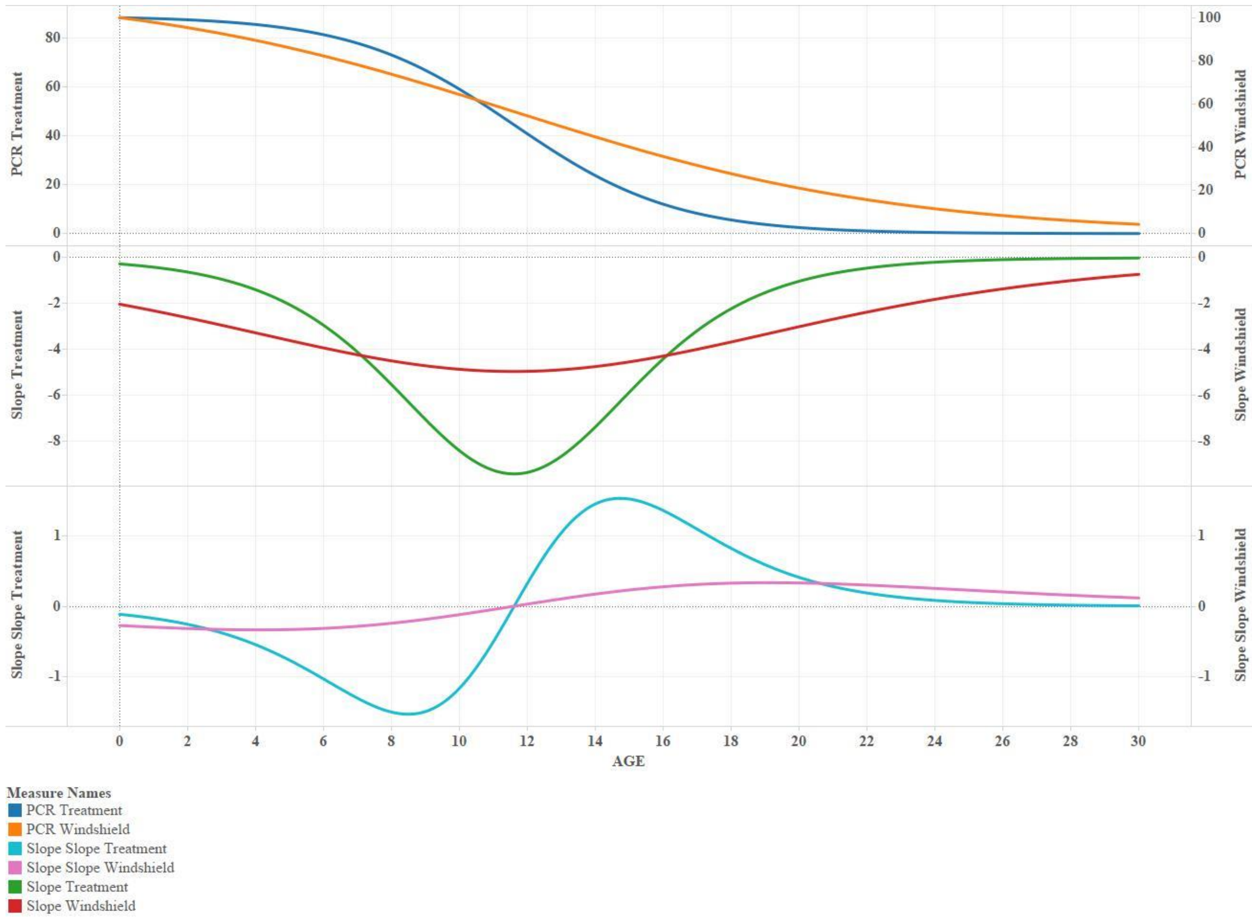
NC 0-1k: *Mill + Resurface* vs. Original



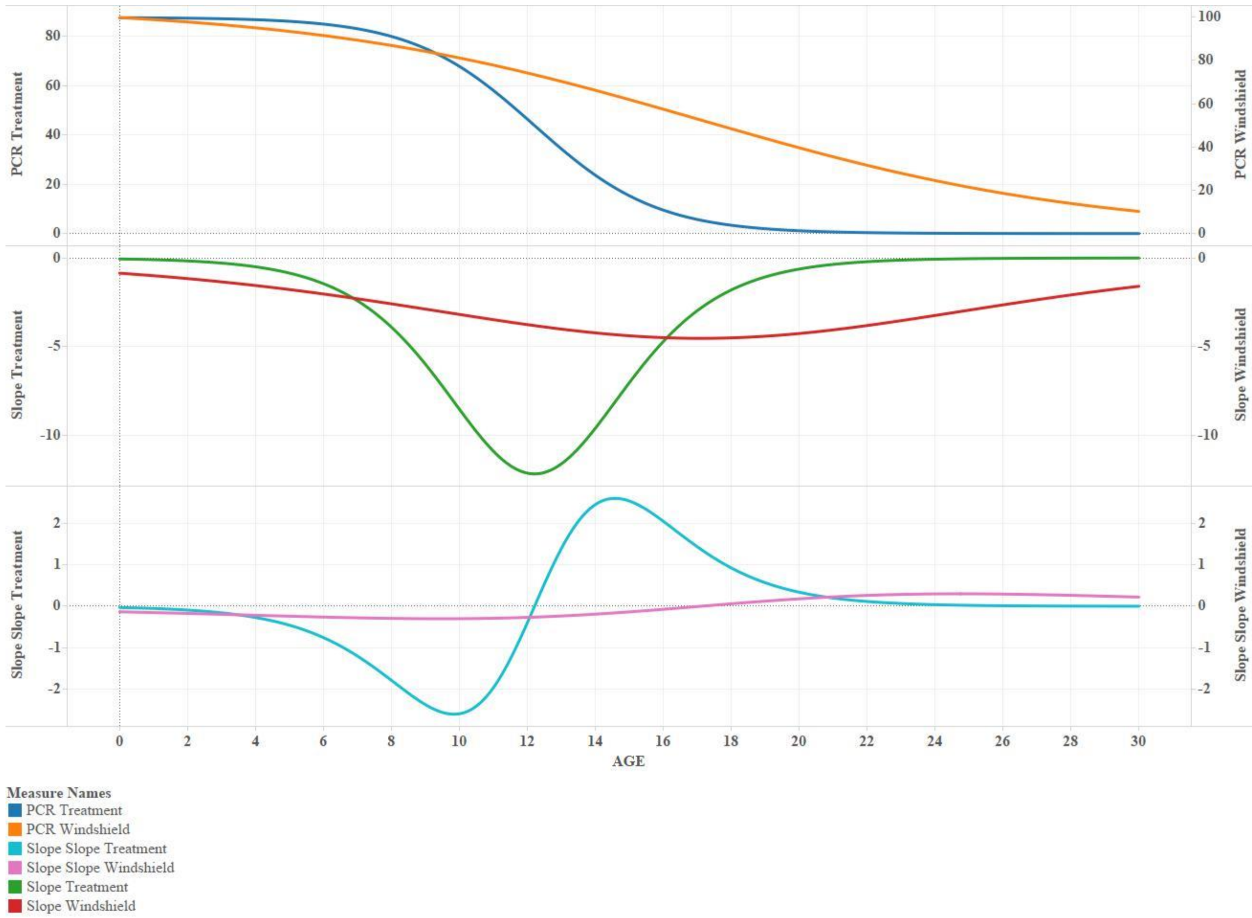
NC 1-5k: *Mill + Resurface* vs. Original



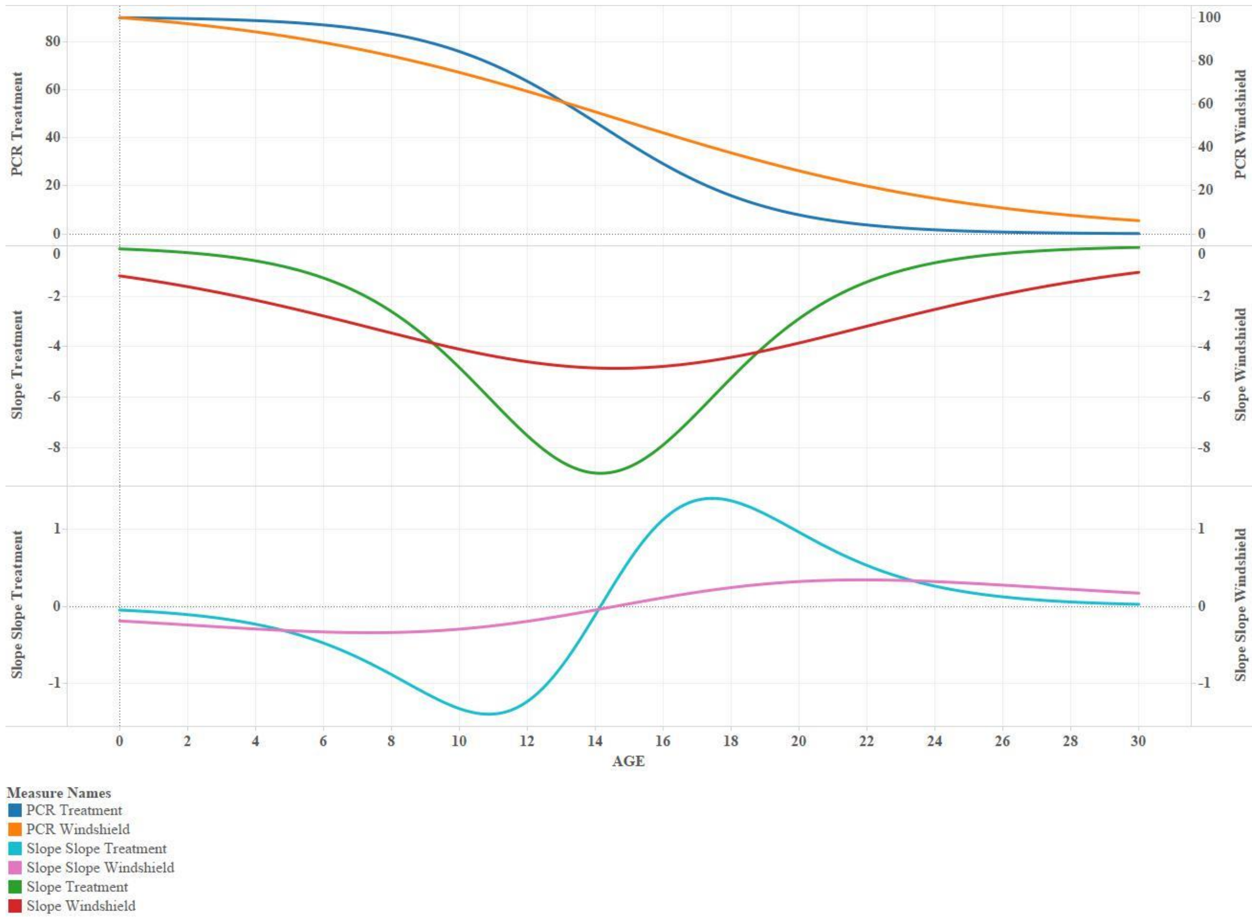
NC 5-15k: *Mill + Resurface* vs. Original



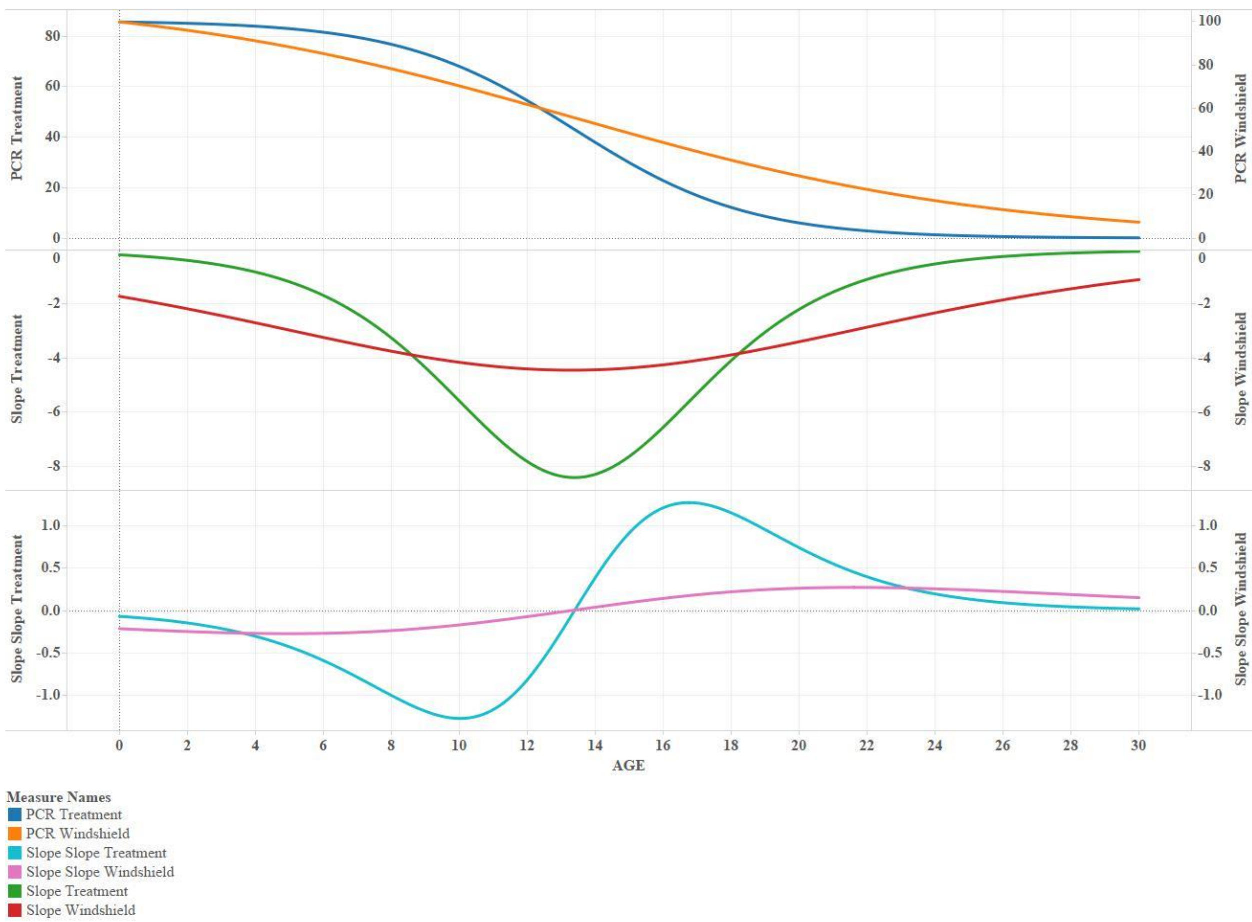
NC 15k+: *Mill + Resurface* vs. Original



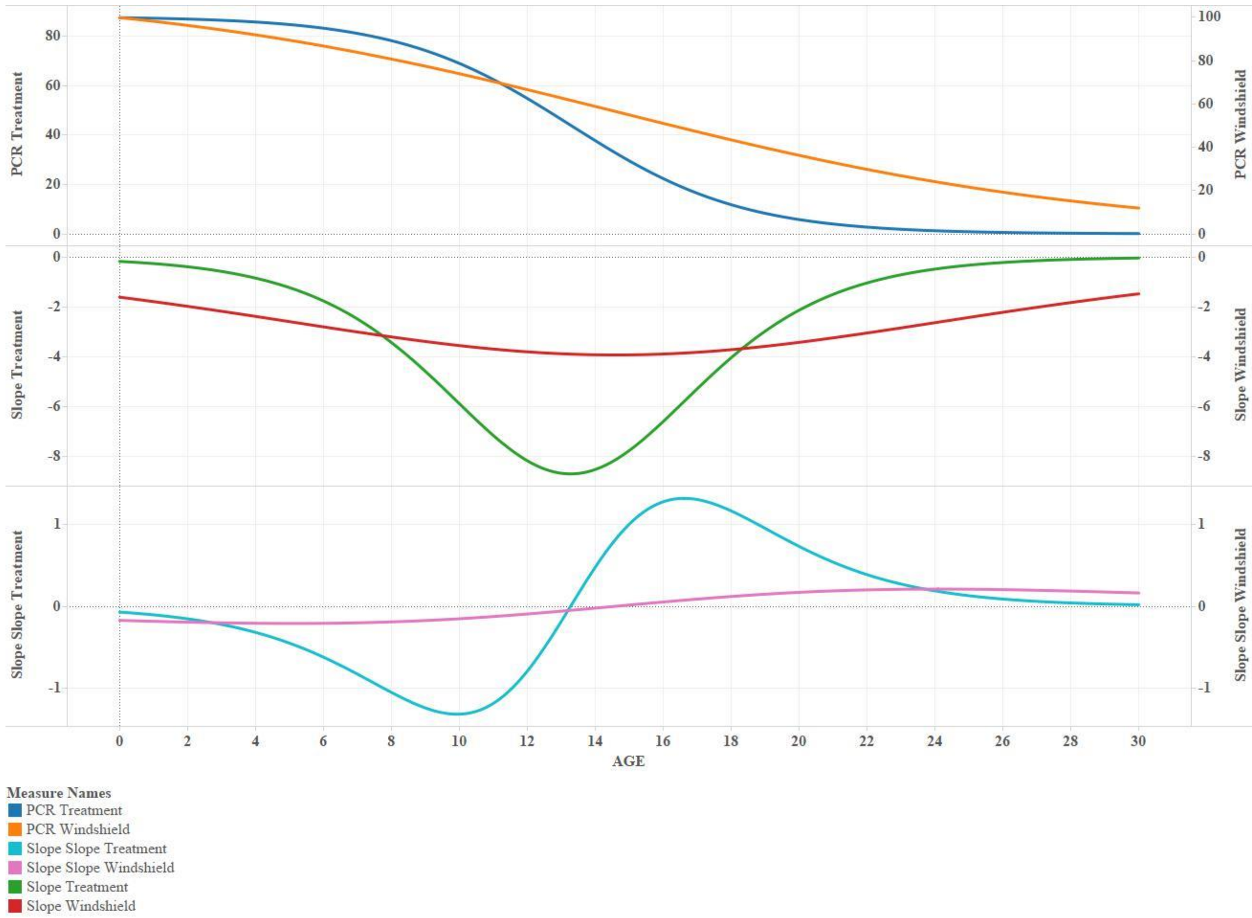
SR 0-1k: *Mill + Resurface* vs. Original



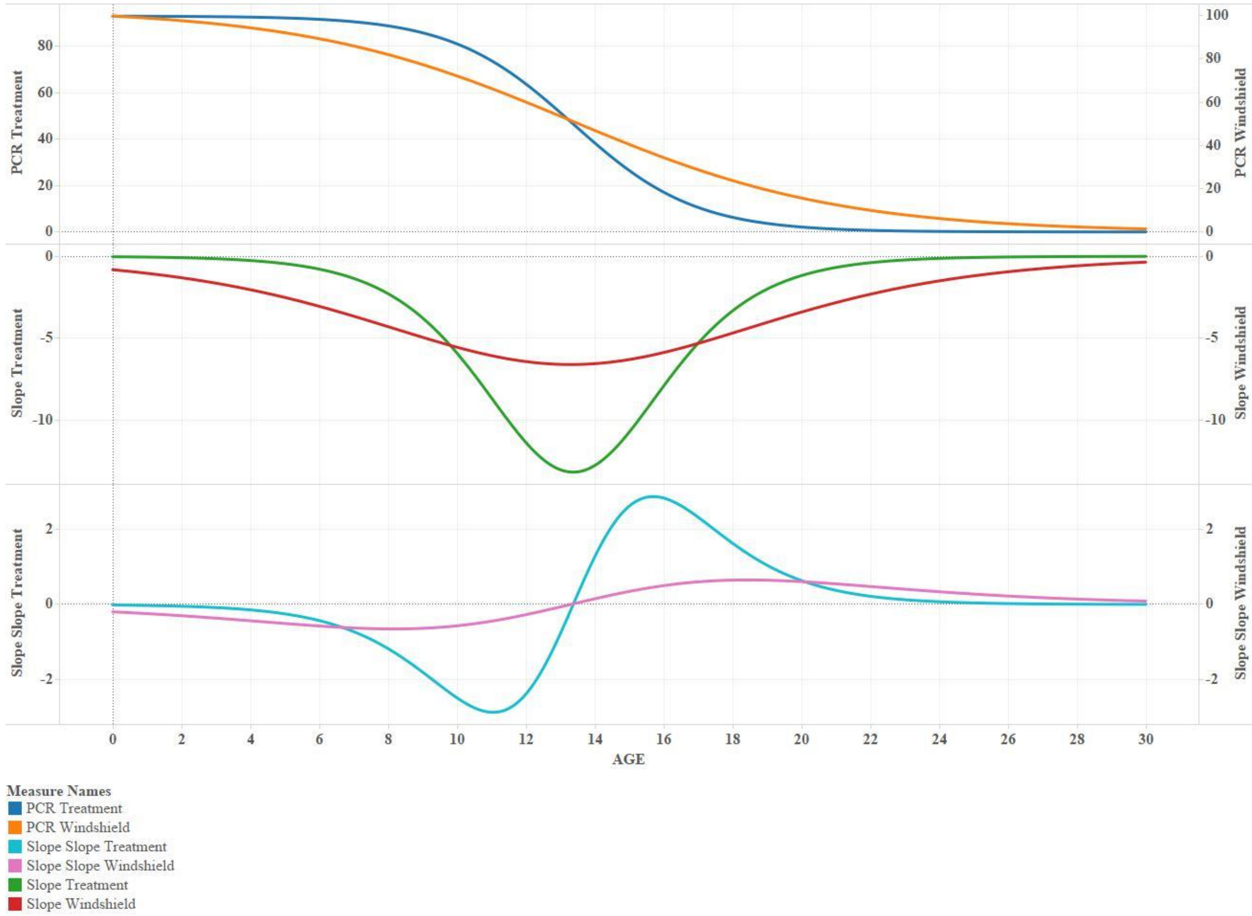
SR 1-5k: *Mill + Resurface* vs. Original



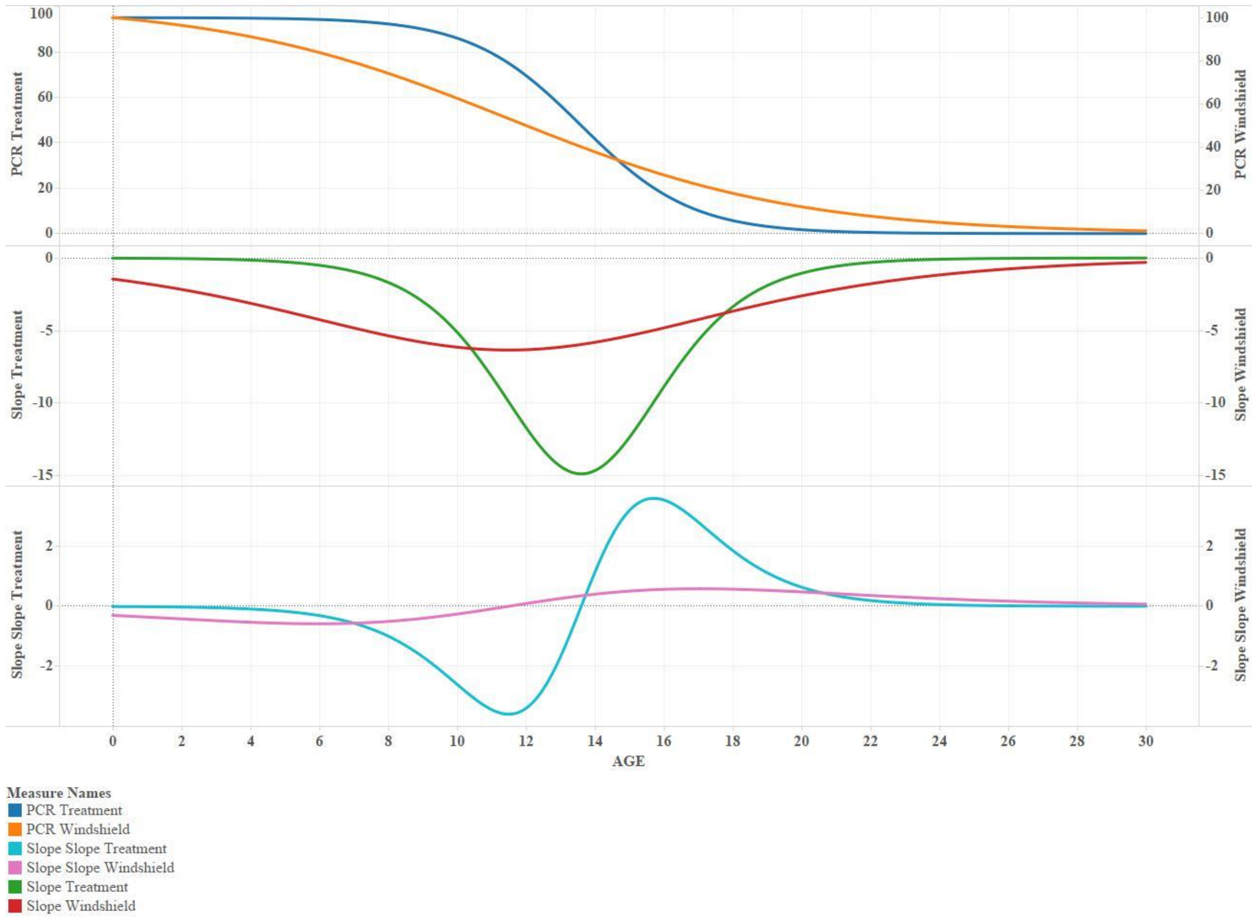
SR 5-15k: *Mill + Resurface* vs. Original



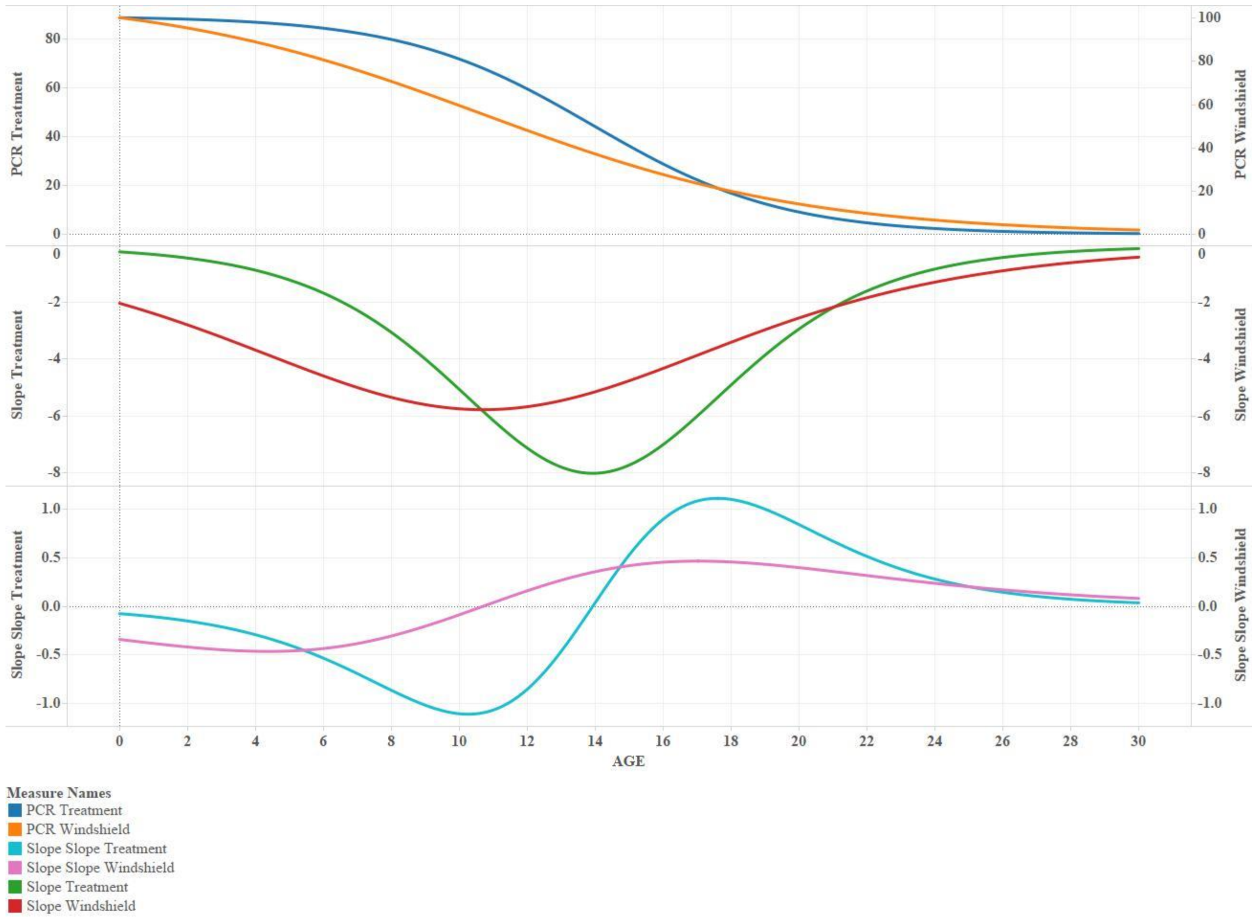
SR 15k+: *Mill + Resurface* vs. Original



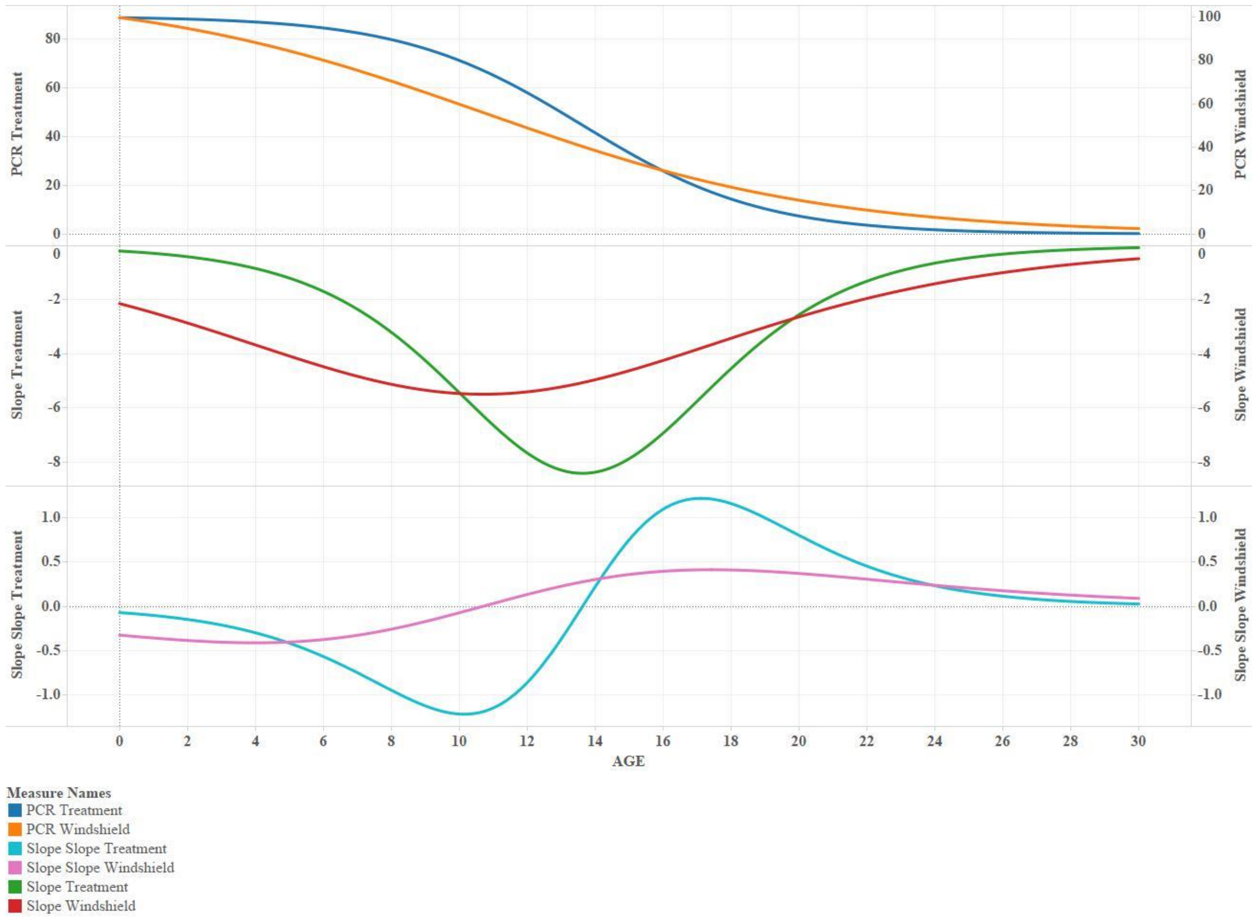
Interstate 0-50k: *Resurface* vs. Original



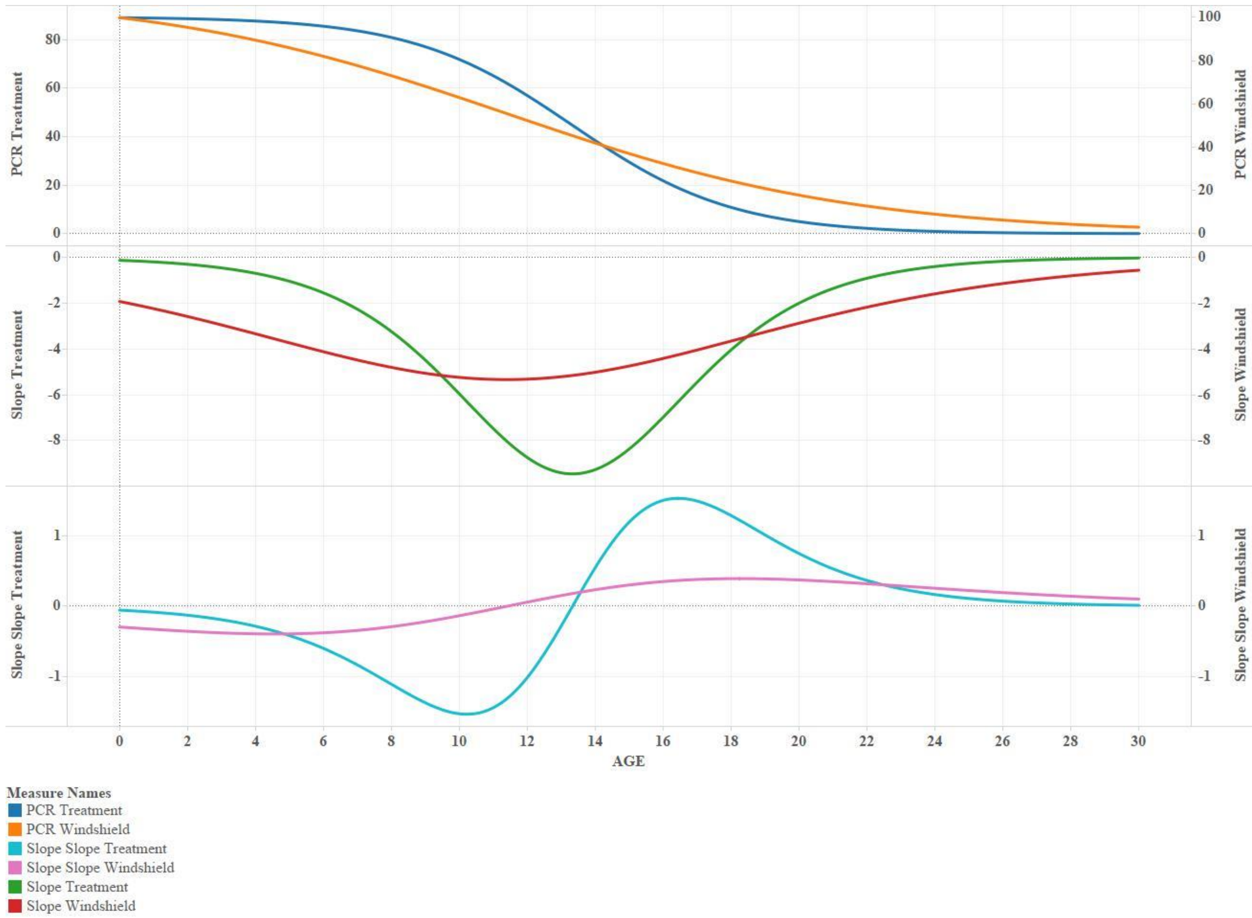
Interstate 50k+: *Resurface* vs. Original



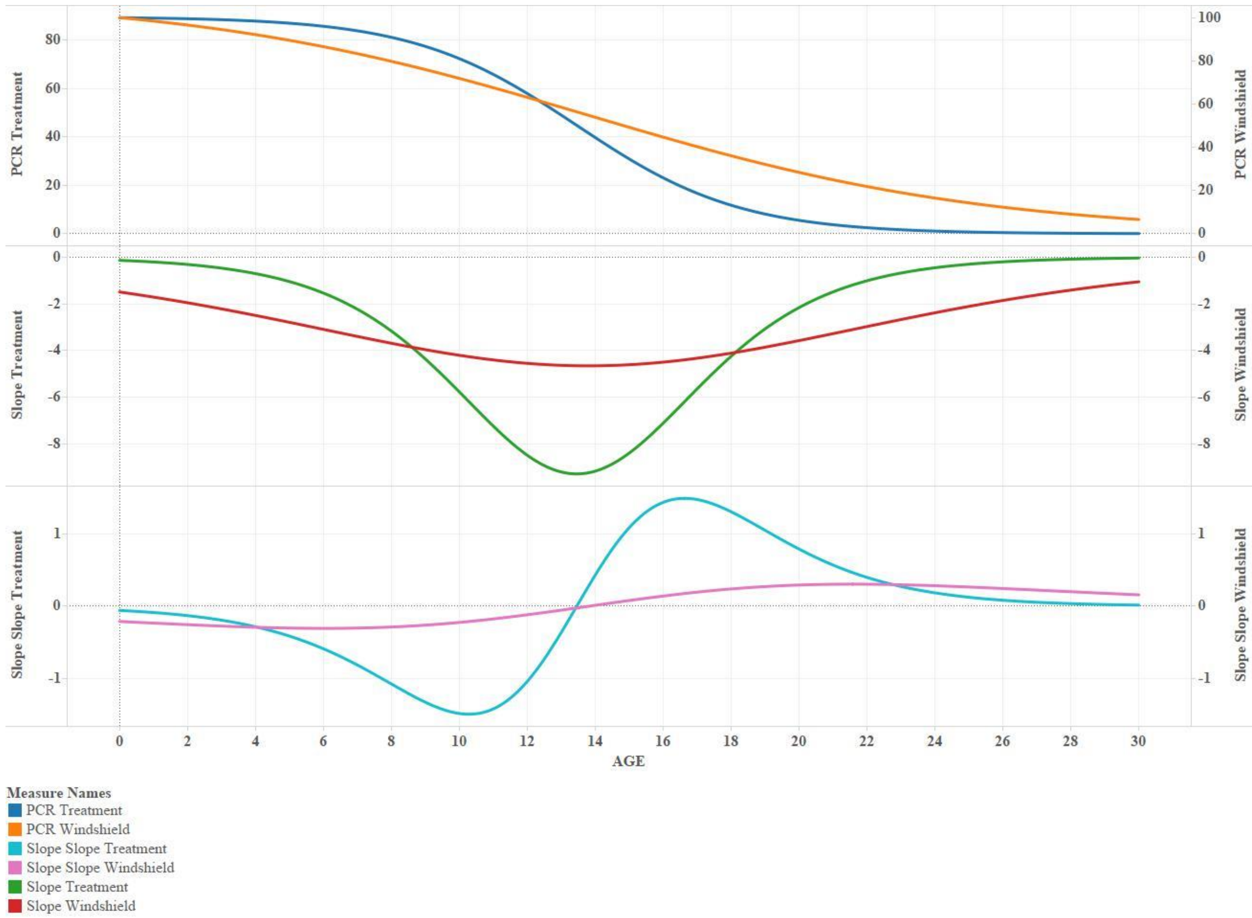
US 0-5k: *Resurface* vs. Original



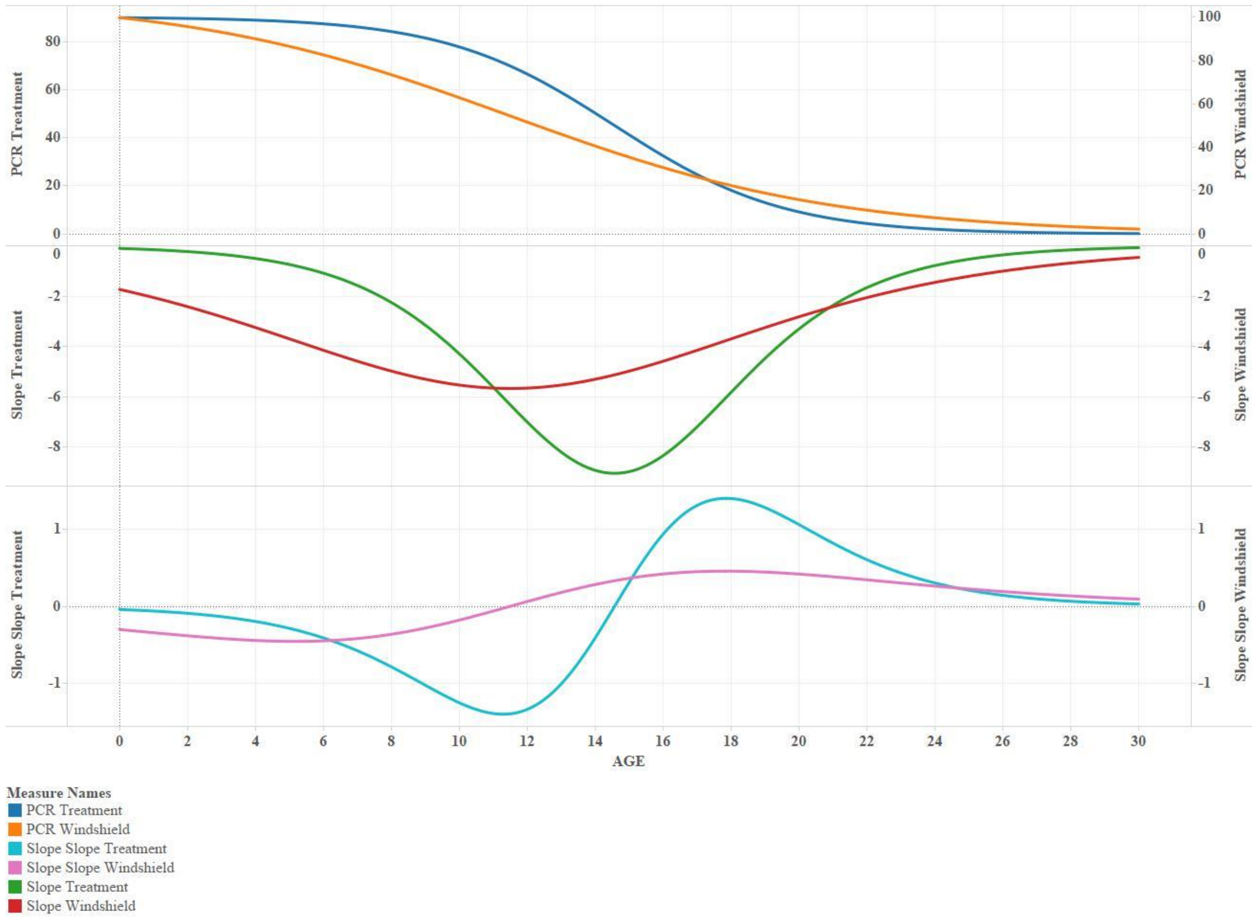
US 5-15k: *Resurface* vs. Original



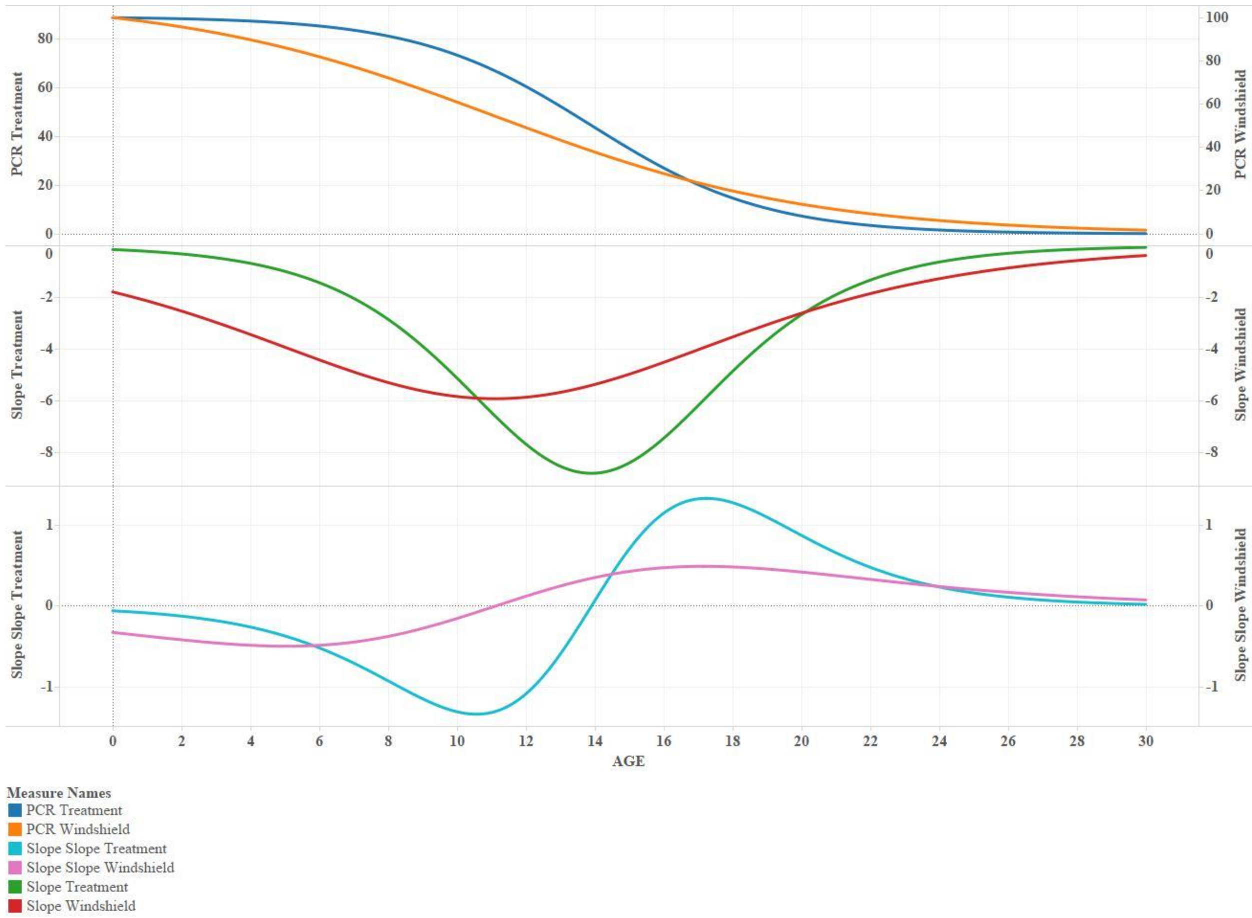
US 15-30k: *Resurface* vs. Original



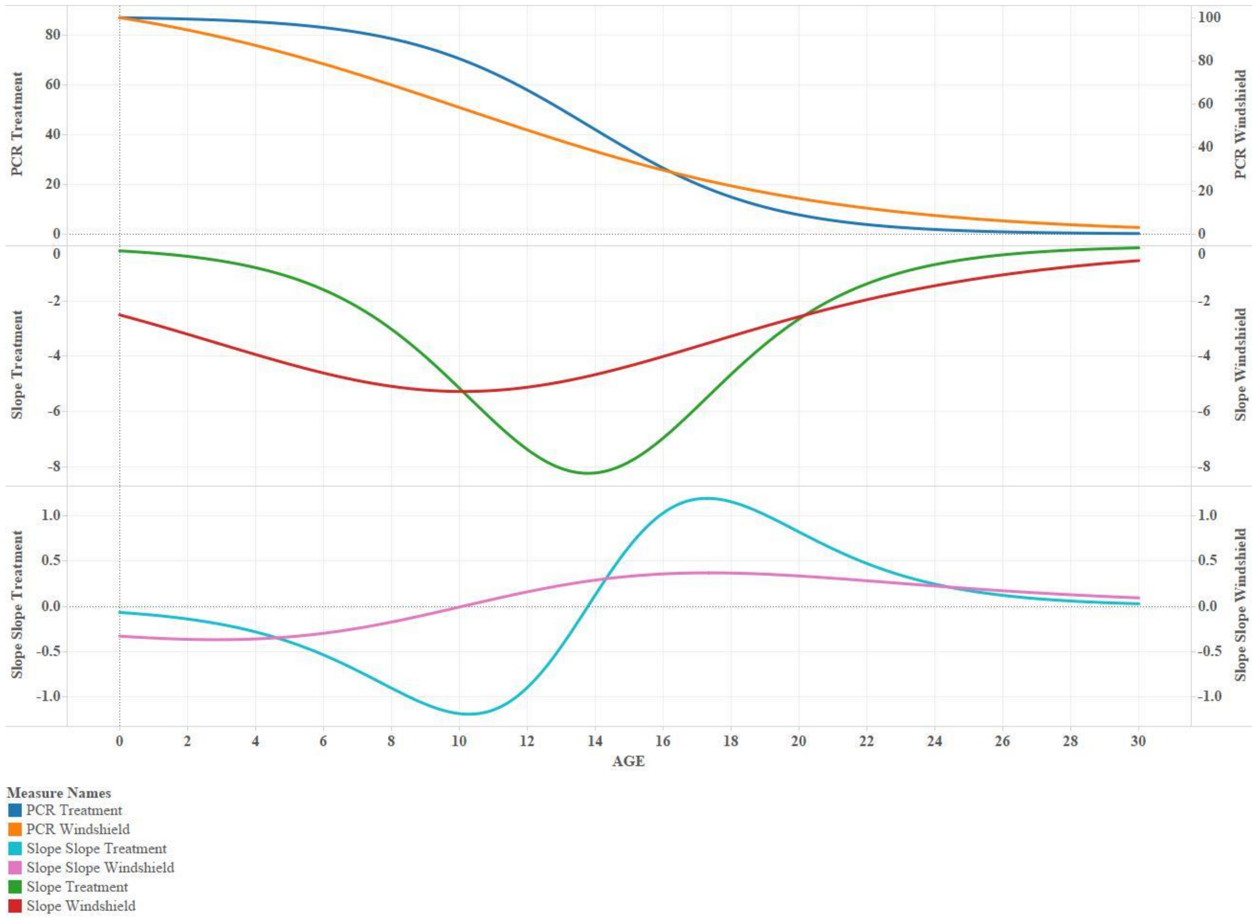
US 30k+: *Resurface* vs. Original



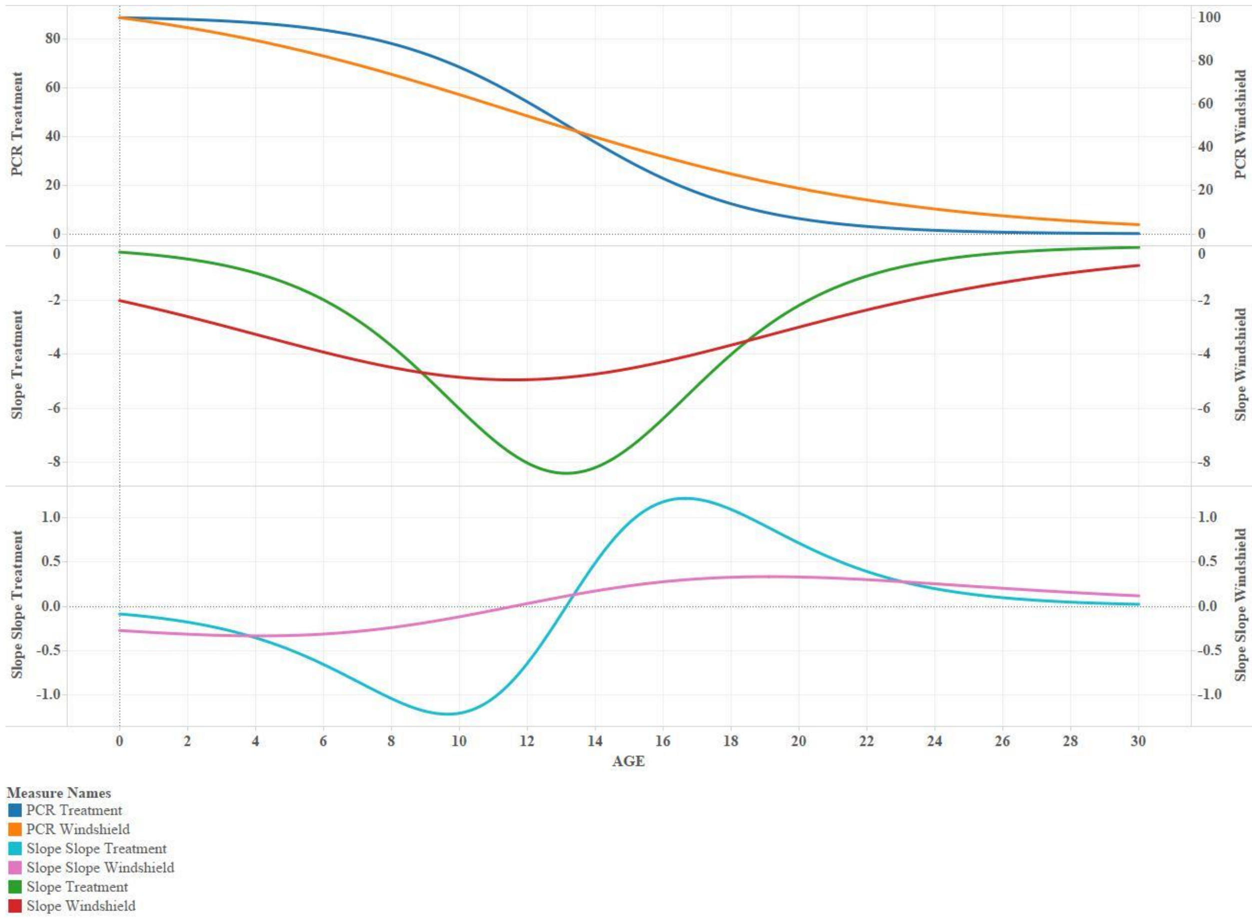
NC 0-1k: *Resurface* vs. Original



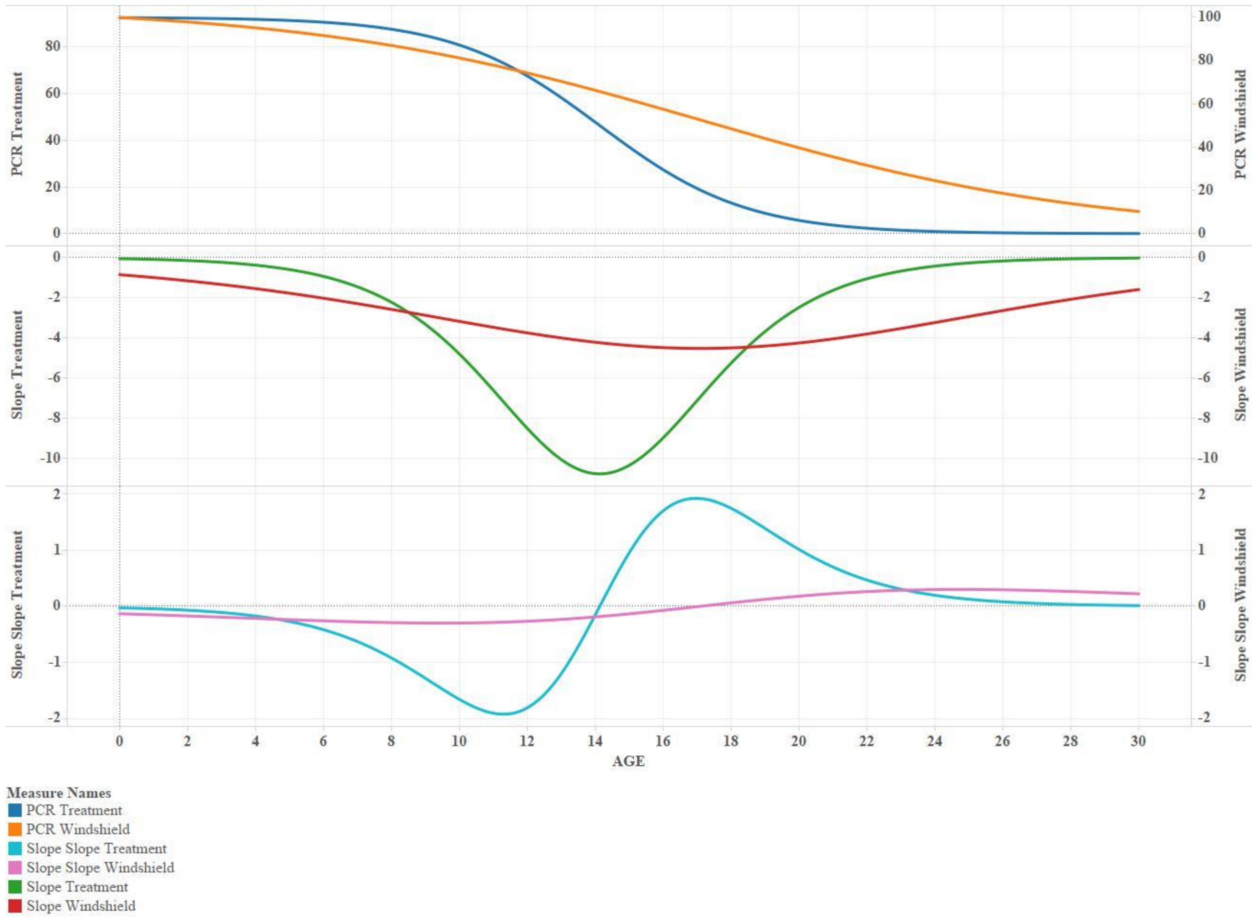
NC 1-5k: *Resurface* vs. Original



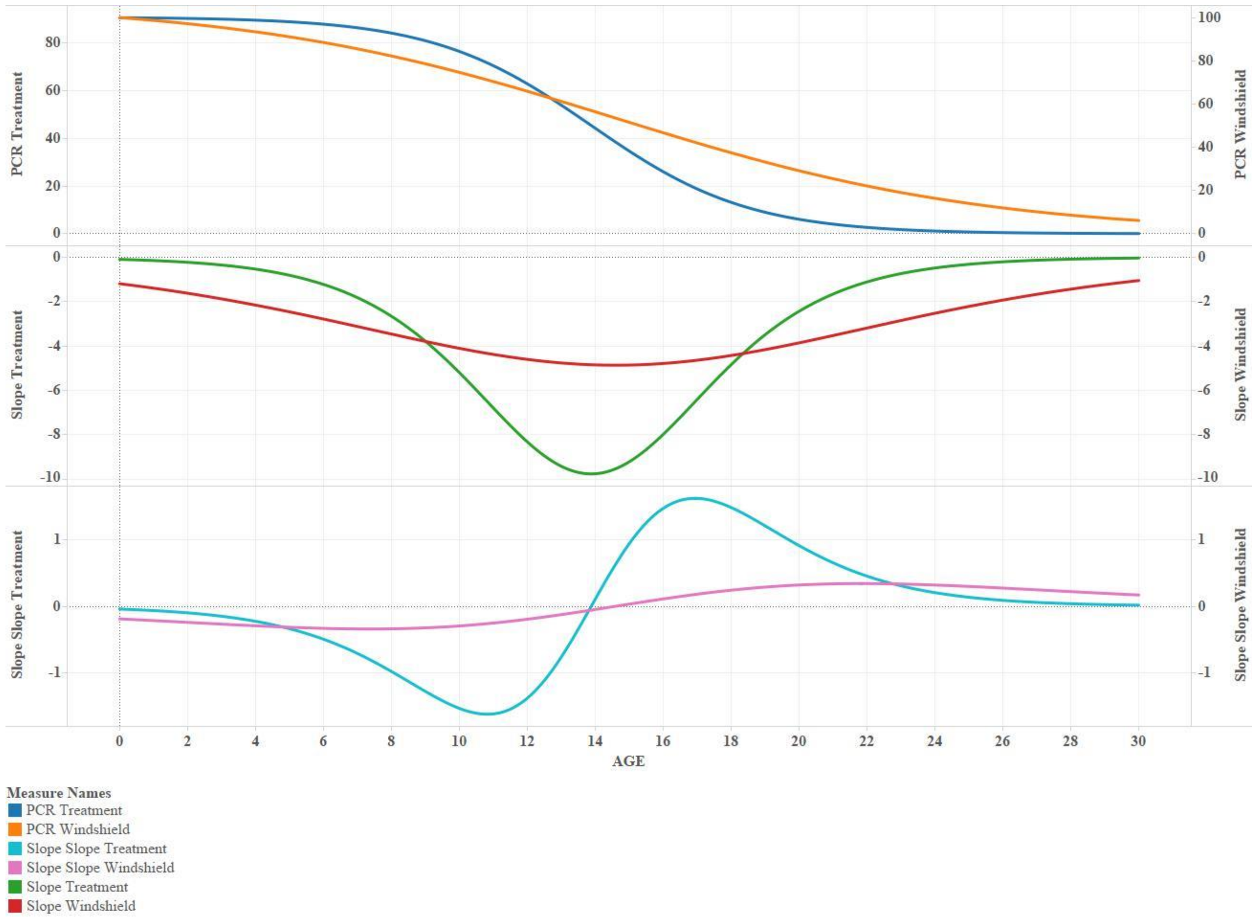
NC 5-15k: *Resurface* vs. Original



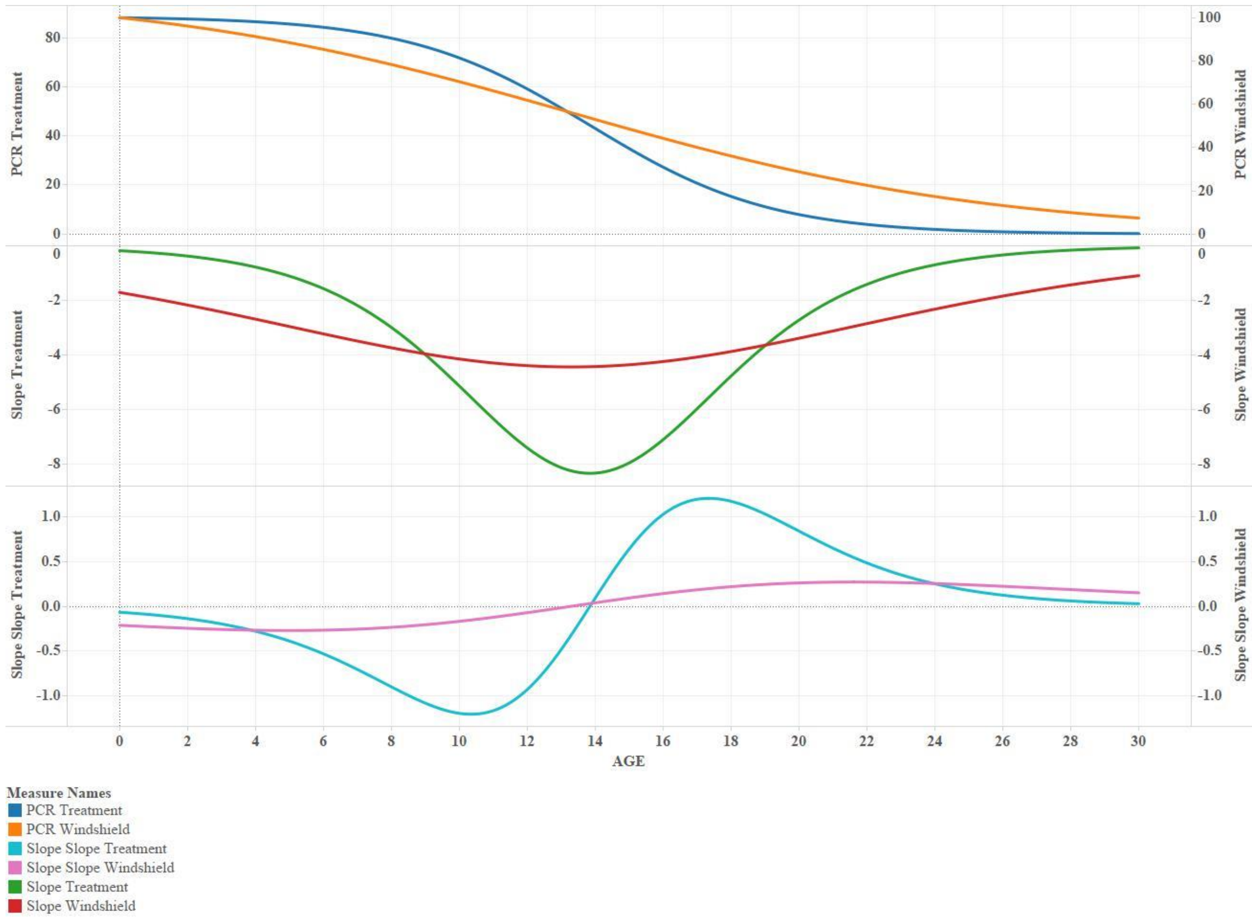
NC 15k+: *Resurface* vs. Original



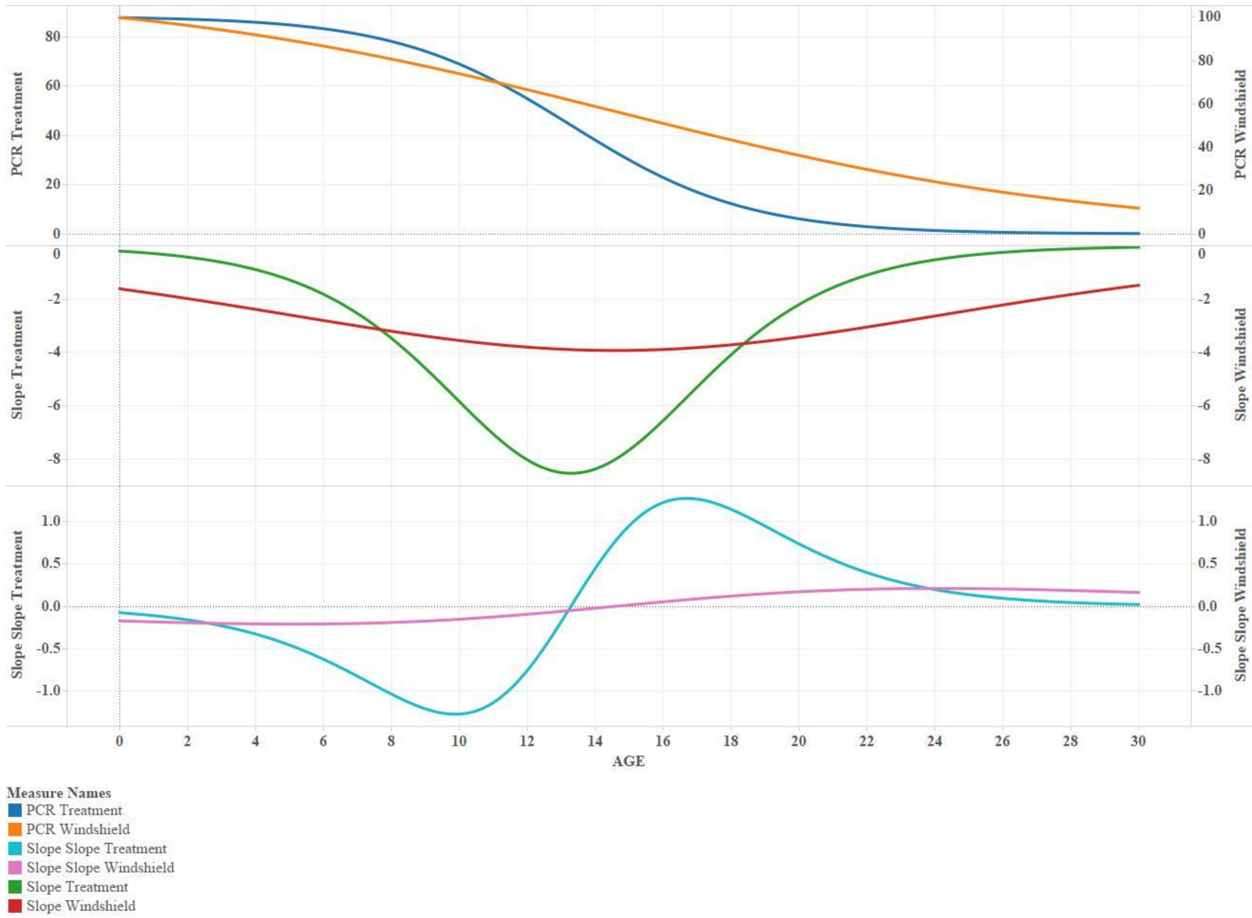
SR 0-1k: *Resurface* vs. Original



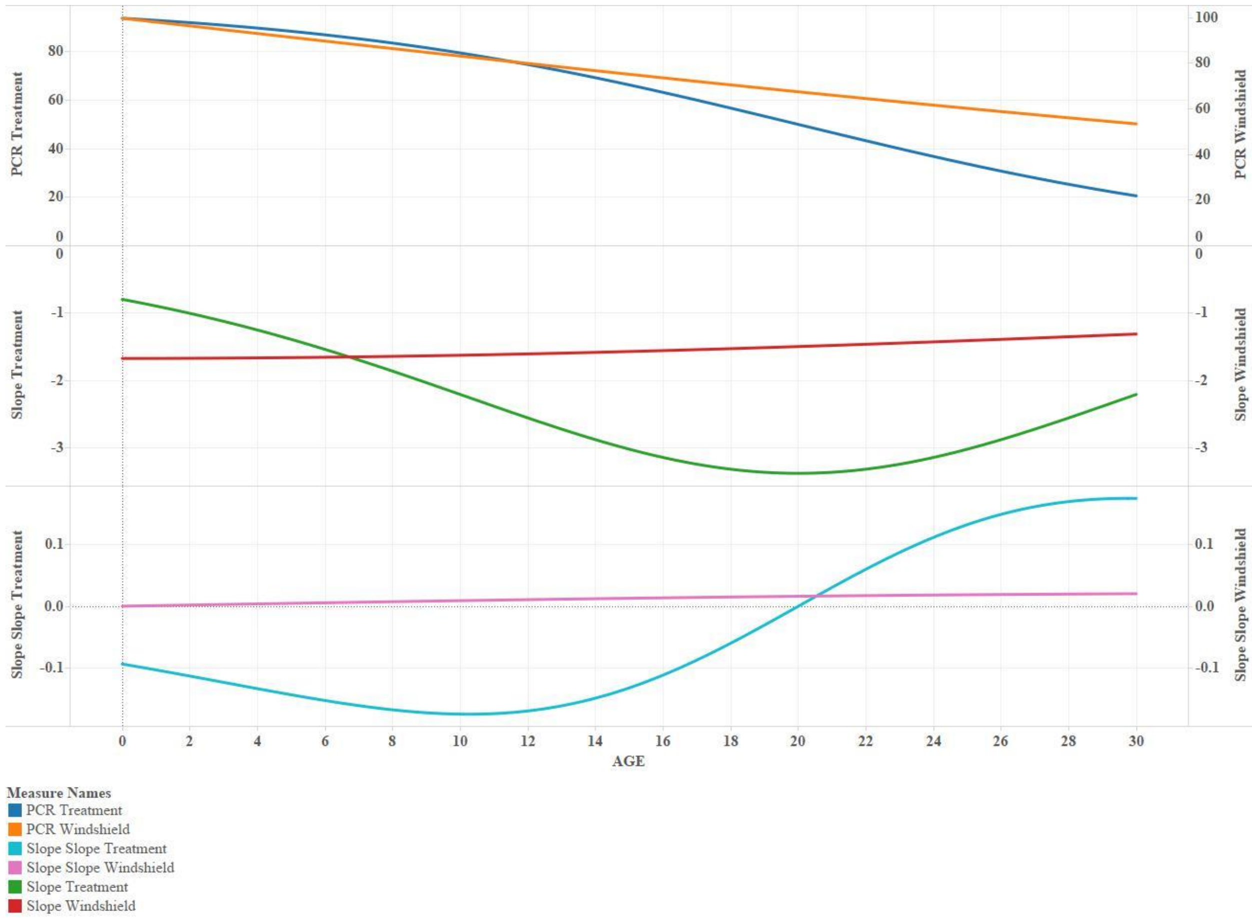
SR 1-5k: *Resurface* vs. Original



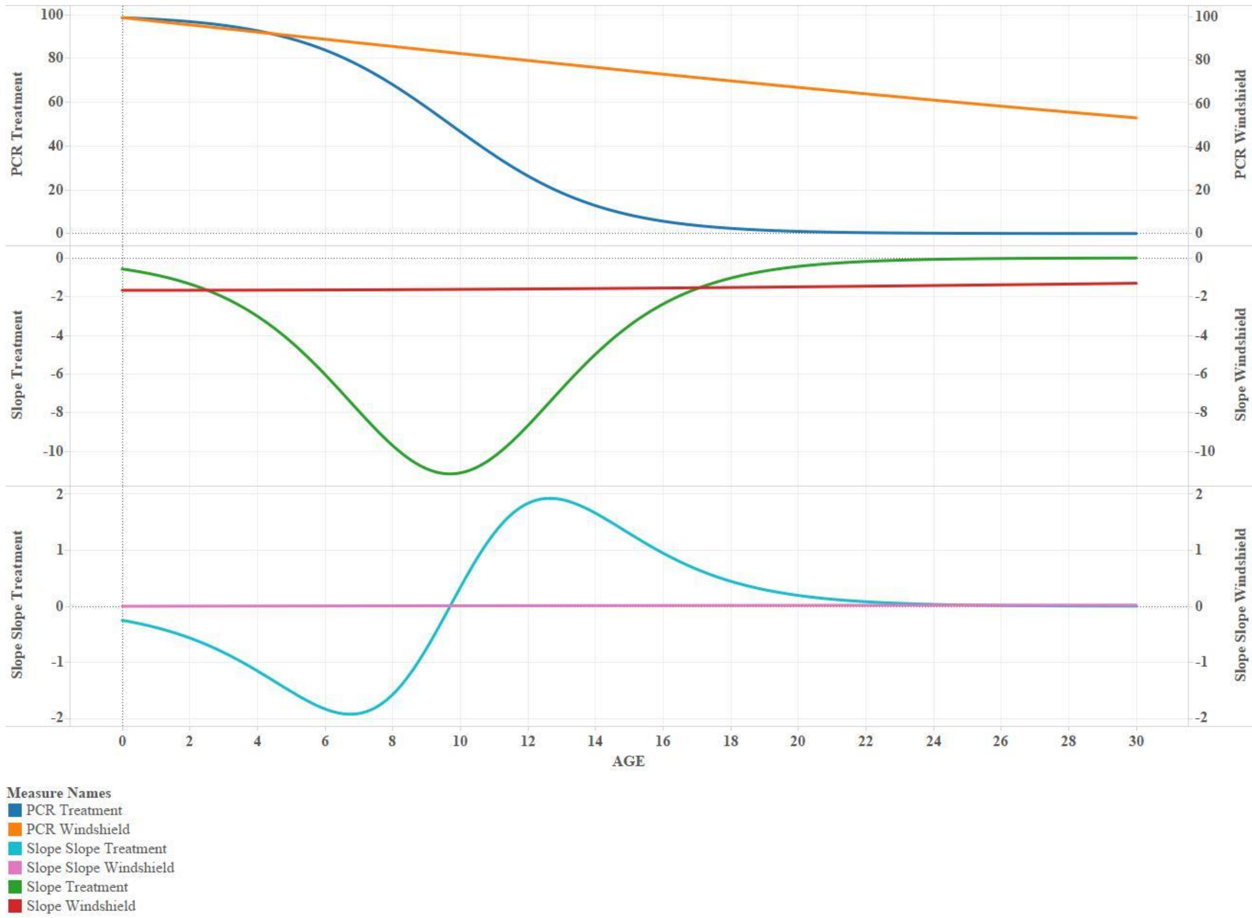
SR 5-15k: *Resurface* vs. Original



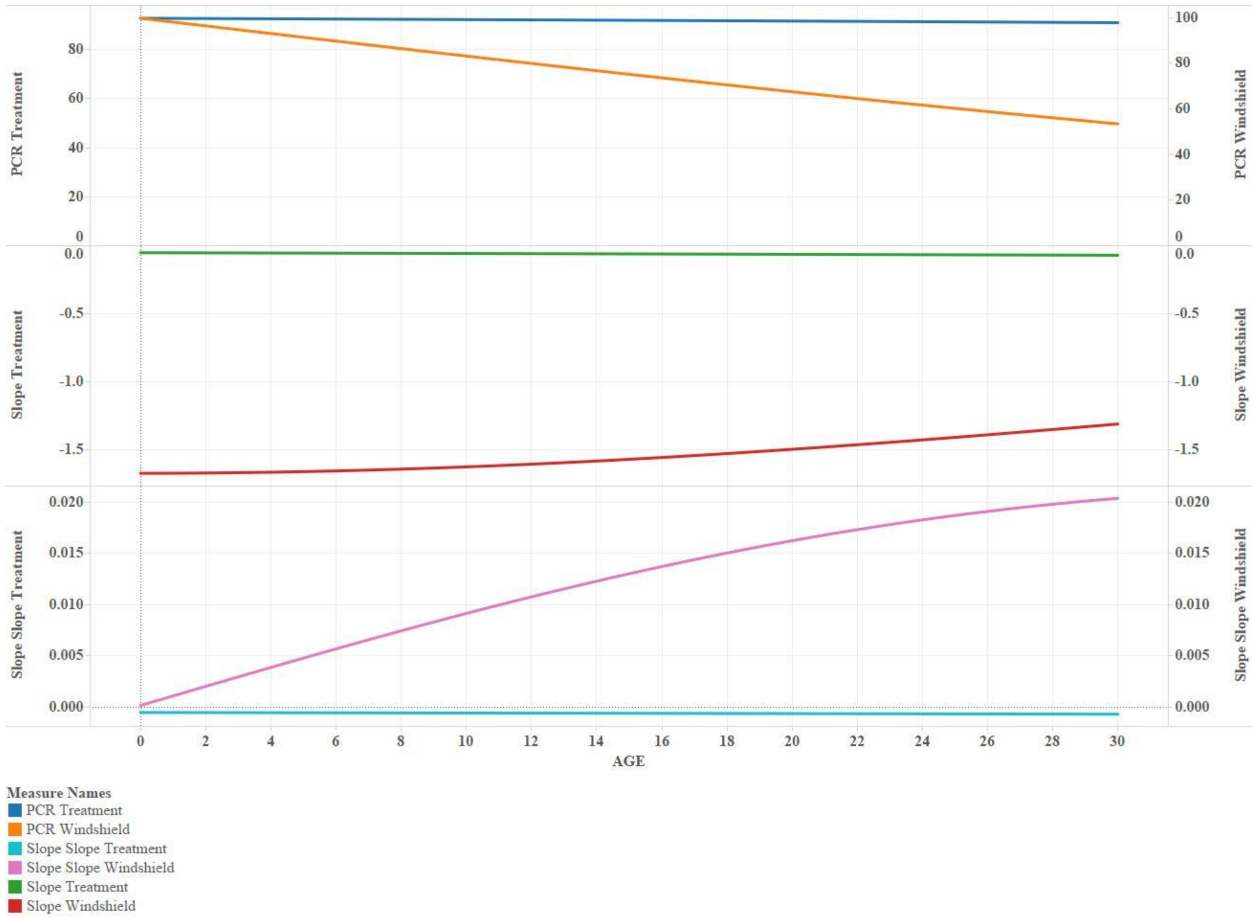
SR 15k+: *Resurface* vs. Original



JCP: *JCP Construction/Reconstruction* vs. Original



JCP: *JCP Minor Rehab* vs. Original



JCP: *Unbonded Concrete Overlay (UBC)* vs. Original