Effect of Vitamin C on Tooth Growth of Guinea Pigs

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Description of experiment:

The response is the length of odontoblasts (teeth) in each of 10 guinea pigs at each of three dose levels of Vitamin C (0.5, 1, and 2 mg) with each of two delivery methods (orange juice or ascorbic acid).
Source: C. I. Bliss (1952) The Statistics of Bioassay. Academic Press.

1. Exploratory Data Analysis

a) Quick overview of the data

Load the ToothGrowth data, necessary libraries and perform some basic analysis.

```
library(datasets)
data(ToothGrowth)
#Dataset summary
str(ToothGrowth)
```

```
## 'data.frame':    60 obs. of  3 variables:
##  $ len : num  4.2 11.5 7.3 5.8 6.4 10 11.2 11.2 5.2 7 ...
##  $ supp: Factor w/ 2 levels "OJ","VC": 2 2 2 2 2 2 2 2 2 2 ...
##  $ dose: num  0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
```

b) Summary of data

60 rows of data - 10 subjects for each case with tooth length measurement (in microns) and varying by:
i) vitamin C supplement - OJ (orange juice) or VC (aqeuous solution)
ii) dose - 0.5, 1.0 and 2.0 mg

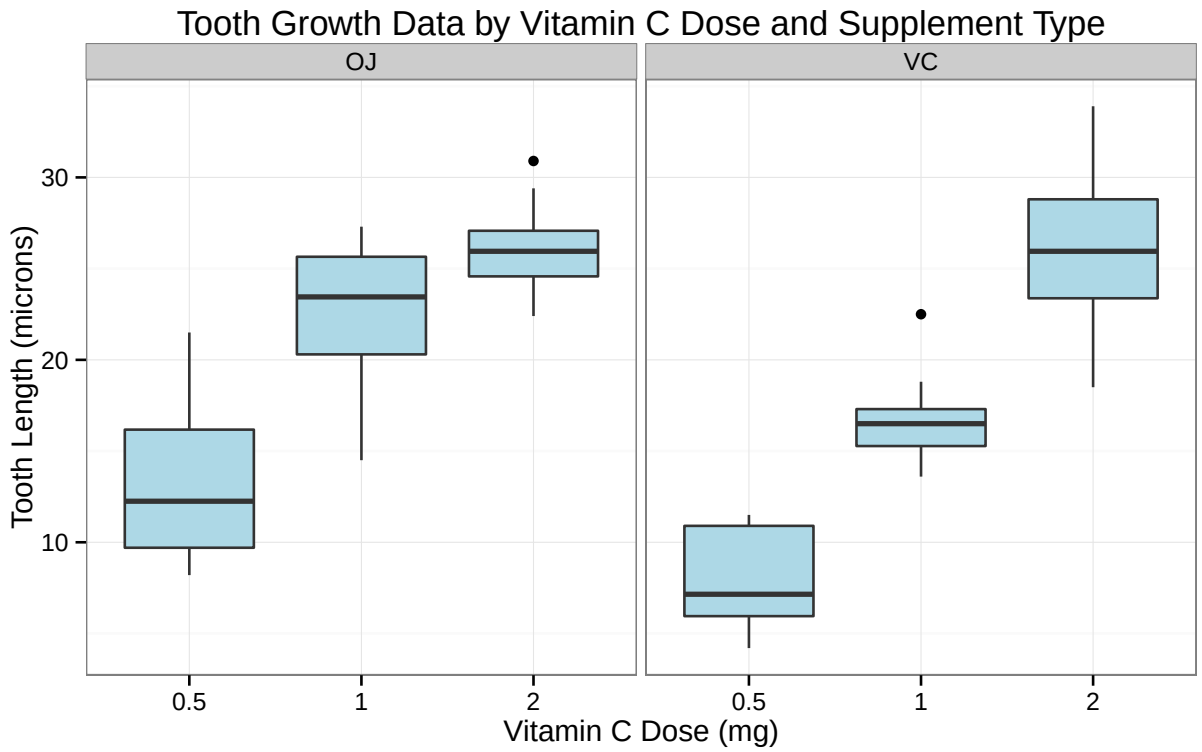
```
# Summarized table for Orange Juice - code in Appendix 1(a)
OJ
```

```
## Source: local data frame [3 x 5]
## Groups: supp
##
##   supp dose subjects avg_length_gain       SD
## 1   OJ  0.5       10           1.323 4.459709
## 2   OJ  1.0       10           2.270 3.910953
## 3   OJ  2.0       10           2.606 2.655058
```

```
#Summarized table for aqueous solution of Vitamin C - code in Appendix 1(a)
VC
```

```
## Source: local data frame [3 x 5]
## Groups: supp
##
##   supp dose subjects avg_length_gain       SD
## 1   VC  0.5       10           0.798 2.746634
## 2   VC  1.0       10           1.677 2.515309
## 3   VC  2.0       10           2.614 4.797731
```

Boxplot to summarize the data (code shown in Appendix 1(b))



Based on the tables and boxplot we can come up with the following observations:
i) Overall average length gain(growth) is higher in subjects fed Orange Juice
ii) Overall increase in the dose results in increases of the average tooth length
iii) For per subject average growth between doses of 1.0 to 2.0 of same supplement , OJ difference is smaller (0.3 microns) compared to VC (0.9 microns)
iv) Average growth per subject peaks at around 2.6 microns for both supplements for dose of 2.0 mg

3. Statistical Inferencing

We use statistical methods to understand if the experiment validly represents the behaviour of the population for the following conclusion:

a) Vitamin C supplement type influences tooth growth of guinea pigs - Compare OJ and VC for similar dose.

Null Hypothesis, *Ho: mean(OJ) - mean(VC) = 0 for same doses*

```
#Create the following vectors to ease calculation  different scenarios:
OJ_05 <- ToothGrowth %>% filter(supp=="OJ", dose == 1.0)%>% select(len)
OJ_1 <- ToothGrowth %>% filter(supp=="OJ", dose == 1.0)%>% select(len)
OJ_2 <- ToothGrowth %>% filter(supp=="OJ", dose == 2.0)%>% select(len)
VC_05 <- ToothGrowth %>% filter(supp=="VC", dose == 0.5)%>% select(len)
VC_1 <- ToothGrowth %>% filter(supp=="VC", dose == 1.0)%>% select(len)
VC_2 <- ToothGrowth %>% filter(supp=="VC", dose == 2.0)%>% select(len)
```

T-Tests OJ vs VC for 95% confidence interval

```
t.test(OJ_05, VC_05, paired = FALSE, var.equal = FALSE)
t.test(OJ_1, VC_1, paired = FALSE, var.equal = FALSE)
t.test(OJ_2, VC_2, paired = FALSE, var.equal = FALSE)
```

Individual results for the tests are shown in Appendix 1

Output of 95% confidence level Student's t-test is summarized in Table 1 below:

Dose(mg)	df	lower-t value	upper t-value	p-value	Result
0.5	16.141	11.51851	17.92149	3.655e-08	Ho is false
1.0	15.358	2.802148	9.057852	0.001038	Ho is false
2.0	14.04	-3.79807	3.63807	0.9639	Ho is true

Remarks Comparing OJ vs VC for similar dosage levels, t-value is greater than 0 and greater than the p-value for 0.5 mg and 1.0 mg respectively. However for 2.0 mg, the t-value lies between 0 and p-value falls in the range. So this means for 2.0 mg there is no significant difference between Vitamin C supplements.

b) Vitamin C supplement improves tooth growth of guinea pigs - Compare by dose

Here OJ and VC results for same dose are combined as a set. This is because the purpose is to see if the dose influences the growth. Assuming the supplement type does not matter because overall growth is directly proportionate to dose for either supplement.

Null Hypothesis:
Ho: mean(d1) - mean(d05) > 0 for dose 0.5 mg compared to 1.0 mg
Ho: mean(d2) - mean(d1) > 0 for dose 2.0 mg compared to 1.0 mg

Create the following vectors to ease calculation for different scenarios:

```
d05 <- ToothGrowth %>% filter(dose == 0.5)%>% select(len)
d1 <- ToothGrowth %>% filter(dose == 1.0)%>% select(len)
d2 <- ToothGrowth %>% filter(dose == 2.0)%>% select(len)
```

T-Tests for 95% confidence interval comparing dosage

```
t.test(d1, d05, paired = FALSE, var.equal = FALSE)
t.test(d2, d1, paired = FALSE, var.equal = FALSE)
```

Individual results for the tests are shown in Appendix 2

Output is summarized in Table 2 below:

Dose(mg)	df	lower-t value	upper t-value	p-value	Result
1.0 vs 0.5	37.986	6.276219	11.983781	1.268e-07	Ho is false
2.0 vs 1.0	37.101	3.733519	8.996481	1.906e-05	Ho is false

Remarks Comparing 1.0 mg vs 0.5 mg and 2.0 mg vs 1.0 mg, t-confidence level is greater than 0 and greater than the p-value. This positively confirms higher dosage results in longer tooth growth for the 95% confidence level and dosage tested.

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4) Conclusions and the assumptions.

The t-value and p-values comparison are sufficient to deduce if Ho is true or false as summarized in the respective tables. Below are the conclusions derived from the statistical inference and data analysis:

a) For dose 0.5 mg and 1.0 mg guinea pigs fed with orange juice have higher tooth growth compared to those fed with aqueous solution of vitamin C.

b) For dose 2.0 mg, both source of vitamin C do not exhibit significant difference on the tooth growth

c) Higher dose of vitamin C positively influences the tooth growth of the guinea pigs

Assumptions: Randomized experiment and variance are unequal

Appendix 1

a) Sumary Table Code

```
OJ<- ToothGrowth %>%  group_by(supp,dose)%>%  filter(supp == "OJ")%>%
   select(supp, dose, len)%>%
        summarize(subjects = length(len),
                  avg_length_gain = mean(len)/length(len), SD = sd(len))

VC<- ToothGrowth %>%   group_by(supp,dose)%>%  filter(supp == "VC")%>%
        select(supp, dose, len)%>%
        summarize(subjects = length(len),
                  avg_length_gain = mean(len)/length(len), SD = sd(len))
```

b) Code for boxplot

```
p <- ggplot(ToothGrowth, aes(factor(dose), len)) + geom_boxplot(fill="lightblue")

p + facet_wrap(~supp, ncol = 2) +
        labs(x="Vitamin C Dose (mg)", y="Tooth Length (microns)",
             title = "Tooth Growth Data by Vitamin C Dose and Supplement Type")+
                theme_bw()
```

Appendix 2

Student's t test ouput for OJ vs VC comparison

```
t.test(OJ_05, VC_05, paired = FALSE, var.equal = FALSE)
```

```
##
##  Welch Two Sample t-test
##
## data:  OJ_05 and VC_05
## t = 9.7401, df = 16.141, p-value = 3.655e-08
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  11.51851 17.92149
## sample estimates:
## mean of x mean of y
##     22.70      7.98
```

```
t.test(OJ_1, VC_1, paired = FALSE, var.equal = FALSE)
```

```
##
##  Welch Two Sample t-test
##
## data:  OJ_1 and VC_1
## t = 4.0328, df = 15.358, p-value = 0.001038
## alternative hypothesis: true difference in means is not equal to 0
```

```
## 95 percent confidence interval:
##  2.802148 9.057852
## sample estimates:
## mean of x mean of y
##     22.70     16.77
```

```
t.test(OJ_2, VC_2, paired = FALSE, var.equal = FALSE)
```

```
##
##  Welch Two Sample t-test
##
## data:  OJ_2 and VC_2
## t = -0.0461, df = 14.04, p-value = 0.9639
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -3.79807  3.63807
## sample estimates:
## mean of x mean of y
##     26.06     26.14
```

Appendix 3

Student's t test ouput for dosage comparison

```
t.test(d1, d05, paired = FALSE, var.equal = FALSE)
```

```
##
##  Welch Two Sample t-test
##
## data:  d1 and d05
## t = 6.4766, df = 37.986, p-value = 1.268e-07
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##   6.276219 11.983781
## sample estimates:
## mean of x mean of y
##    19.735    10.605
```

```
t.test(d2, d1, paired = FALSE, var.equal = FALSE)
```

```
##
##  Welch Two Sample t-test
##
## data:  d2 and d1
## t = 4.9005, df = 37.101, p-value = 1.906e-05
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  3.733519 8.996481
## sample estimates:
## mean of x mean of y
##    26.100    19.735
```