Longitudinal HW1

# 1.Data Summary

Read BMACS data

library(lme4)

## Loading required package: Matrix

BMACS <- read.csv("D:/luxinyve/00 Longitudinal Data/homework1/BMACS.csv",header=T)  
str(BMACS)

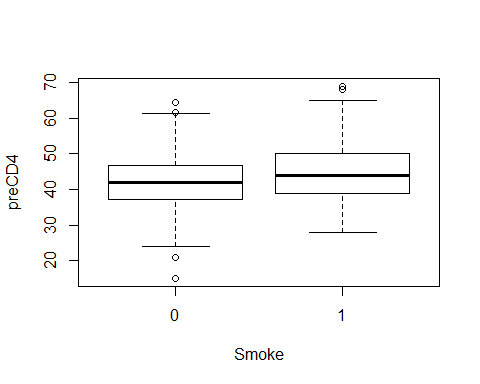
## 'data.frame': 1817 obs. of 6 variables:  
## $ ID : int 1022 1022 1022 1022 1022 1022 1022 1049 1049 1049 ...  
## $ Time : num 0.2 0.8 1.2 1.6 2.5 3 4.1 0.3 0.6 1 ...  
## $ Smoke : int 0 0 0 0 0 0 0 0 0 0 ...  
## $ age : num 26.2 26.2 26.2 26.2 26.2 ...  
## $ preCD4: num 38 38 38 38 38 38 38 44.5 44.5 44.5 ...  
## $ CD4 : num 17 30 23 15 21 12 5 37 44 37 ...

summary(BMACS)

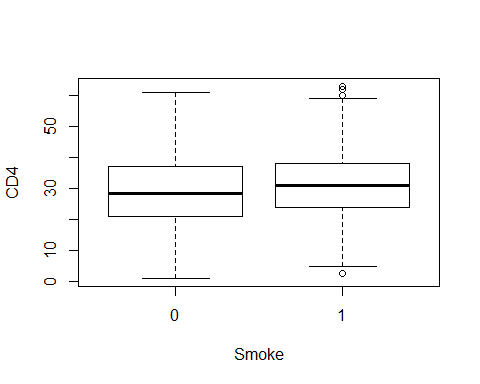
## ID Time Smoke age   
## Min. :1022 Min. :0.100 Min. :0.000 Min. :18.25   
## 1st Qu.:3334 1st Qu.:1.000 1st Qu.:0.000 1st Qu.:29.17   
## Median :5075 Median :2.200 Median :0.000 Median :32.58   
## Mean :5401 Mean :2.347 Mean :0.311 Mean :34.36   
## 3rd Qu.:7744 3rd Qu.:3.500 3rd Qu.:1.000 3rd Qu.:39.00   
## Max. :9954 Max. :5.900 Max. :1.000 Max. :59.92   
## preCD4 CD4   
## Min. :15.00 Min. : 1.00   
## 1st Qu.:37.67 1st Qu.:21.20   
## Median :42.33 Median :29.00   
## Mean :42.69 Mean :29.26   
## 3rd Qu.:47.12 3rd Qu.:37.00   
## Max. :69.00 Max. :63.00

Use boxplot to show the relationship between CD4 and Smoke. It showed that people who always smoked had higher preCD4 and CD4.

boxplot(BMACS$preCD4~BMACS$Smoke,xlab="Smoke",ylab="preCD4")



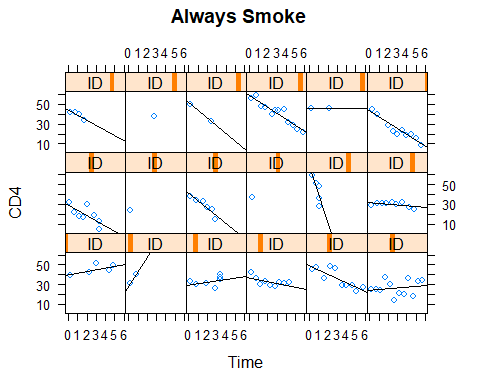
boxplot(BMACS$CD4~BMACS$Smoke,xlab="Smoke",ylab="CD4")



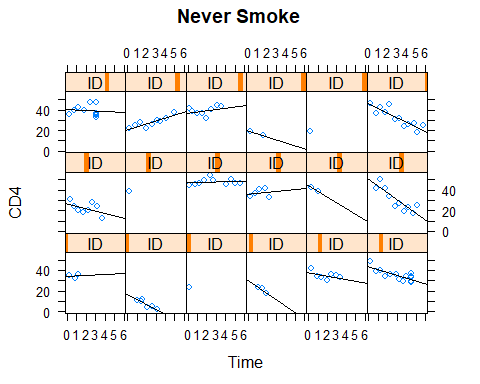
Plot the relationship of CD4 and Time. Choose 18 candidates from each smoking group. For both groups of the people, no matter they smoke heavily or never, most people’s CD4 went down or nearly unchanged as time passed by.

Always Smoke

set.seed(1)  
library(lattice)  
BMACS=as.data.frame(BMACS)   
Smoke1 <- sample(unique(BMACS$ID[BMACS$Smoke==1]),18)   
Smoke1.18=BMACS[is.element(BMACS$ID,Smoke1),]   
xyplot(CD4~Time|ID,data=Smoke1.18,main="Always Smoke",xlab="Time",ylab="CD4",  
 layout=c(6,3),panel=function(x,y){  
 panel.xyplot(x,y)  
 panel.lmline(x,y)})

 Never Smoke

Smoke0 <- sample(unique(BMACS$ID[BMACS$Smoke==0]),18)   
Smoke0.18=BMACS[is.element(BMACS$ID,Smoke0),]   
xyplot(CD4~Time|ID,data=Smoke0.18,main="Never Smoke",xlab="Time",ylab="CD4",  
 layout=c(6,3),panel=function(x,y){  
 panel.xyplot(x,y)  
 panel.lmline(x,y)})



If we fit CD4 and Time with simple linear regression modles for each patient, most of the slopes of Time was negative, which prooved the above conclusion.

lr1=lmList(CD4~Time|ID,subset=Smoke==1,data=BMACS)   
head(coef(lr1))

## (Intercept) Time  
## 1126 39.65189 1.806795  
## 1265 24.82000 18.400000  
## 1298 29.06217 -2.255773  
## 1308 44.52326 -3.545325  
## 1359 35.00000 NA  
## 1505 50.24554 -6.032773

lr0=lmList(CD4~Time|ID,subset=Smoke==0,data=BMACS)   
head(coef(lr0))

## (Intercept) Time  
## 1022 25.76424 -4.2798248  
## 1049 39.30046 -4.3893884  
## 1120 43.61689 -0.2771174  
## 1212 25.66667 -13.3333333  
## 1219 41.45794 -6.3382353  
## 1235 37.52175 -8.2307977

summary(coef(lr0))

## (Intercept) Time   
## Min. :-5.00 Min. :-32.500   
## 1st Qu.:27.32 1st Qu.: -4.766   
## Median :34.18 Median : -2.550   
## Mean :34.73 Mean : -3.210   
## 3rd Qu.:41.22 3rd Qu.: -0.409   
## Max. :69.75 Max. : 36.667   
## NA's :14

summary(coef(lr1))

## (Intercept) Time   
## Min. : 5.20 Min. :-33.0000   
## 1st Qu.:30.37 1st Qu.: -5.8409   
## Median :36.74 Median : -2.8596   
## Mean :37.41 Mean : -3.8083   
## 3rd Qu.:43.22 3rd Qu.: -0.3479   
## Max. :83.03 Max. : 18.4000   
## NA's :14

# 2.Fit Models Define: yij: The post CD4 for the ith patient in the jth measurment. tij: Time of the jth measurement for the ith patient si = sij: Smoking status for the ith patient pi = pij: PreCD4 for the ith patient

# 2.1 First Task: post-infection CD4 as a function of time

First, we consider a simple linear mixed-efects model of post-infection CD4 as a function of time since HIV-infection and use the two-stage modeling approach. Model Expression: First stage:

Second stage:

$$α\_{1i} = b\_{1i} + β'\_{1}Z\_i \\ α\_{2i} = b\_{2i} + β'\_{2}Z\_i $$

is the intercept, is the slope. and are the ﬁxed coeffcient vectors. is the baseline covariates matrix for the ith patient ∼ N(0,) is the measurement error # 2.1.1 Only random intercept # (a) Smoking status only Model Expression: First stage:

$$y\_{ij} = α\_{1i} + α2\_it\_{ij} +\epsilon\_{ij},\space j =1,2,··· ,n\_i$$

Second stage:

$$α\_{1i} = β\_0 + b\_{0i} +β\_1s\_i \\ α\_{2i} = β\_{2} $$

Combination:

$$y\_{ij} = β\_0 + b\_{0i} +β\_1s\_i + β\_{2}t\_{ij} +\epsilon\_{ij}, \space j =1,2,··· ,n\_i$$

si is the smoking status for the ith patient. β0,β1,β2 are the ﬁxed effect vector. β0 is the average post-CD4 level at the begining time for non-smokers. β0 + β1 is the average post-CD4 level at the begining time for smokers. β2 is average slope of time.

model2.1.1.a <- lmer(CD4 ~ 1 + Time + Smoke + (1|ID), data = BMACS)  
summary(model2.1.1.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Smoke + (1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12548.8  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.7275 -0.5760 -0.0394 0.5680 4.5534   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 77.28 8.791   
## Residual 40.26 6.345   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 34.6481 0.7271 47.649  
## Time -2.6709 0.1076 -24.813  
## Smoke 2.0075 1.1595 1.731  
##   
## Correlation of Fixed Effects:  
## (Intr) Time   
## Time -0.305   
## Smoke -0.575 0.021

# (b) pre-CD4 level only

model2.1.1.b <- lmer(CD4 ~ 1 + Time + preCD4 + (1|ID), data = BMACS)  
summary(model2.1.1.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + preCD4 + (1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12521.5  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.8120 -0.5762 -0.0281 0.5802 4.4741   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 67.90 8.240   
## Residual 40.24 6.343   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 18.53122 2.78267 6.66  
## Time -2.66454 0.10740 -24.81  
## preCD4 0.39204 0.06344 6.18  
##   
## Correlation of Fixed Effects:  
## (Intr) Time   
## Time -0.089   
## preCD4 -0.979 0.012

# (c) both smoking status and pre-CD4

model2.1.1.c <- lmer(CD4 ~ 1 + Time + Smoke + preCD4 + (1|ID), data = BMACS)  
summary(model2.1.1.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Smoke + preCD4 + (1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12519  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.8048 -0.5761 -0.0262 0.5793 4.4790   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 68.03 8.248   
## Residual 40.24 6.343   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 18.60160 2.78678 6.675  
## Time -2.66302 0.10743 -24.790  
## Smoke 0.81423 1.11434 0.731  
## preCD4 0.38357 0.06454 5.943  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Smoke   
## Time -0.088   
## Smoke 0.035 0.020   
## preCD4 -0.969 0.008 -0.180

# (d) Summary of only random intercept

anova(model2.1.1.a,model2.1.1.b,model2.1.1.c,refit=F)

## Data: BMACS  
## Models:  
## model2.1.1.a: CD4 ~ 1 + Time + Smoke + (1 | ID)  
## model2.1.1.b: CD4 ~ 1 + Time + preCD4 + (1 | ID)  
## model2.1.1.c: CD4 ~ 1 + Time + Smoke + preCD4 + (1 | ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.1.1.a 5 12559 12586 -6274.4 12549   
## model2.1.1.b 5 12532 12559 -6260.8 12522 27.2425 0 <2e-16 \*\*\*  
## model2.1.1.c 6 12531 12564 -6259.5 12519 2.5879 1 0.1077   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.1.2 Only random slope

# (a) Smoking status only

model2.1.2.a <- lmer(CD4 ~ 1 + Time + Smoke + (Time-1|ID), data = BMACS)  
summary(model2.1.2.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Smoke + (Time - 1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12768.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.7788 -0.5584 -0.0119 0.5414 3.8732   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID Time 13.62 3.691   
## Residual 47.58 6.898   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 35.3590 0.3740 94.538  
## Time -3.1370 0.2858 -10.976  
## Smoke 1.6504 0.6026 2.739  
##   
## Correlation of Fixed Effects:  
## (Intr) Time   
## Time -0.368   
## Smoke -0.524 -0.035

# (b) pre-CD4 level only

model2.1.2.b <- lmer(CD4 ~ 1 + Time + preCD4 + (Time-1|ID), data = BMACS)  
summary(model2.1.2.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + preCD4 + (Time - 1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12578.5  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.8322 -0.5637 -0.0120 0.5558 3.9629   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID Time 13.64 3.693   
## Residual 42.11 6.489   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 15.7190 1.4062 11.18  
## Time -3.2288 0.2813 -11.48  
## preCD4 0.4732 0.0322 14.70  
##   
## Correlation of Fixed Effects:  
## (Intr) Time   
## Time -0.068   
## preCD4 -0.977 -0.027

# (c) both smoking status and pre-CD4

model2.1.2.c <- lmer(CD4 ~ 1 + Time + Smoke + preCD4 + (Time-1|ID), data = BMACS)  
summary(model2.1.2.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Smoke + preCD4 + (Time - 1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12577.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.8255 -0.5694 -0.0135 0.5522 3.9447   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID Time 13.66 3.696   
## Residual 42.11 6.490   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 15.73525 1.40687 11.185  
## Time -3.23447 0.28168 -11.483  
## Smoke 0.34161 0.58042 0.589  
## preCD4 0.47019 0.03261 14.417  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Smoke   
## Time -0.068   
## Smoke 0.022 -0.033   
## preCD4 -0.968 -0.021 -0.157

# (d) Summary of only random slope

anova(model2.1.2.a,model2.1.2.b,model2.1.2.c,refit=F)

## Data: BMACS  
## Models:  
## model2.1.2.a: CD4 ~ 1 + Time + Smoke + (Time - 1 | ID)  
## model2.1.2.b: CD4 ~ 1 + Time + preCD4 + (Time - 1 | ID)  
## model2.1.2.c: CD4 ~ 1 + Time + Smoke + preCD4 + (Time - 1 | ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)  
## model2.1.2.a 5 12778 12806 -6384.2 12768   
## model2.1.2.b 5 12588 12616 -6289.3 12578 189.9289 0 <2e-16  
## model2.1.2.c 6 12589 12622 -6288.7 12577 1.0959 1 0.2952  
##   
## model2.1.2.a   
## model2.1.2.b \*\*\*  
## model2.1.2.c   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.1.3 Both random intercept and ramdom slope:

# (a) Smoking status only

model2.1.3.a <- lmer(CD4 ~ 1 + Time + Smoke + (Time|ID), data = BMACS)  
summary(model2.1.3.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Smoke + (Time | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12149  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.1993 -0.5481 -0.0219 0.5205 4.2324   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 77.438 8.800   
## Time 9.329 3.054 -0.32  
## Residual 25.031 5.003   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 35.0357 0.7060 49.624  
## Time -3.0826 0.2355 -13.090  
## Smoke 1.9986 1.1017 1.814  
##   
## Correlation of Fixed Effects:  
## (Intr) Time   
## Time -0.359   
## Smoke -0.558 -0.002

# (b) pre-CD4 level only

model2.1.3.b <- lmer(CD4 ~ 1 + Time + preCD4 + (Time|ID), data = BMACS)  
summary(model2.1.3.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + preCD4 + (Time | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12102.7  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.2278 -0.5437 -0.0141 0.5250 4.3257   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 58.590 7.654   
## Time 9.428 3.070 -0.25  
## Residual 24.989 4.999   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 15.88791 2.54974 6.231  
## Time -3.10264 0.23641 -13.124  
## preCD4 0.46352 0.05816 7.970  
##   
## Correlation of Fixed Effects:  
## (Intr) Time   
## Time -0.078   
## preCD4 -0.979 -0.004

# (c) both smoking status and pre-CD4

model2.1.3.c <- lmer(CD4 ~ 1 + Time + Smoke + preCD4 + (Time|ID), data = BMACS)  
summary(model2.1.3.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Smoke + preCD4 + (Time | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12100.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.2258 -0.5449 -0.0140 0.5258 4.3168   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 58.743 7.664   
## Time 9.436 3.072 -0.25  
## Residual 24.985 4.998   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 15.93566 2.55409 6.239  
## Time -3.10390 0.23650 -13.124  
## Smoke 0.65610 1.02195 0.642  
## preCD4 0.45699 0.05913 7.729  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Smoke   
## Time -0.078   
## Smoke 0.031 -0.008   
## preCD4 -0.969 -0.003 -0.174

# (d) Summary of random both

anova(model2.1.3.a,model2.1.3.b,model2.1.3.c,refit=F)

## Data: BMACS  
## Models:  
## model2.1.3.a: CD4 ~ 1 + Time + Smoke + (Time | ID)  
## model2.1.3.b: CD4 ~ 1 + Time + preCD4 + (Time | ID)  
## model2.1.3.c: CD4 ~ 1 + Time + Smoke + preCD4 + (Time | ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.1.3.a 7 12163 12202 -6074.5 12149   
## model2.1.3.b 7 12117 12155 -6051.4 12103 46.2838 0 <2e-16 \*\*\*  
## model2.1.3.c 8 12116 12160 -6050.2 12100 2.2926 1 0.13   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.2 Second Task

To allow some ﬂexibility, we next consider the linear mixed-effect model of post-CD4 as a polynomial function of time since HIV-infection. Using the two-stage modeling approach

BMACS$Time2=BMACS$Time^2

# 2.2.1 Only random intercept

# (a) Smoking status only

model2.2.1.a=lmer(CD4~1 + Time + Time2 + Smoke + (1|ID), data = BMACS)   
summary(model2.2.1.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Time2 + Smoke + (1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12521.2  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.8791 -0.5602 -0.0238 0.5537 4.3608   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 76.96 8.773   
## Residual 39.52 6.286   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 36.31304 0.78314 46.369  
## Time -4.63168 0.36548 -12.673  
## Time2 0.36336 0.06479 5.608  
## Smoke 1.97176 1.15622 1.705  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Time2   
## Time -0.444   
## Time2 0.379 -0.956   
## Smoke -0.535 0.011 -0.006

# (b) pre-CD4 level only

model2.2.1.b <- lmer(CD4 ~ 1 + Time + Time2 + preCD4 + (1|ID), data = BMACS)  
summary(model2.2.1.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Time2 + preCD4 + (1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12493.2  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.9032 -0.5589 -0.0127 0.5666 4.2790   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 67.42 8.211   
## Residual 39.49 6.284   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 20.09881 2.78464 7.218  
## Time -4.64647 0.36478 -12.738  
## Time2 0.36744 0.06470 5.679  
## preCD4 0.39446 0.06317 6.244  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Time2   
## Time -0.121   
## Time2 0.099 -0.956   
## preCD4 -0.974 -0.003 0.007

# (c) both smoking status and pre-CD4

model2.2.1.c <- lmer(CD4 ~ 1 + Time + Time2 + Smoke + preCD4 + (1|ID), data = BMACS)  
summary(model2.2.1.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Time2 + Smoke + preCD4 + (1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12490.7  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.9070 -0.5569 -0.0135 0.5674 4.2839   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 67.56 8.220   
## Residual 39.49 6.284   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 20.16378 2.78888 7.230  
## Time -4.64325 0.36482 -12.727  
## Time2 0.36711 0.06470 5.674  
## Smoke 0.76977 1.10968 0.694  
## preCD4 0.38646 0.06428 6.012  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Time2 Smoke   
## Time -0.120   
## Time2 0.099 -0.956   
## Smoke 0.034 0.013 -0.007   
## preCD4 -0.963 -0.005 0.008 -0.180

# (d) Summary of only random intercept

anova(model2.2.1.a,model2.2.1.b,model2.2.1.c,refit=F)

## Data: BMACS  
## Models:  
## model2.2.1.a: CD4 ~ 1 + Time + Time2 + Smoke + (1 | ID)  
## model2.2.1.b: CD4 ~ 1 + Time + Time2 + preCD4 + (1 | ID)  
## model2.2.1.c: CD4 ~ 1 + Time + Time2 + Smoke + preCD4 + (1 | ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.2.1.a 6 12533 12566 -6260.6 12521   
## model2.2.1.b 6 12505 12538 -6246.6 12493 28.0355 0 <2e-16 \*\*\*  
## model2.2.1.c 7 12505 12543 -6245.3 12491 2.5267 1 0.1119   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.2.2 Only random slope

# (a) Smoking status only

model2.2.2.a <- lmer(CD4 ~ 1 + Time + Time2 + Smoke:Time + (Time-1|ID), data = BMACS)  
summary(model2.2.2.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Time2 + Smoke:Time + (Time - 1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12761.3  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.9235 -0.5453 -0.0037 0.5383 3.6726   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID Time 13.39 3.660   
## Residual 47.40 6.885   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 37.11488 0.43959 84.430  
## Time -4.85800 0.50040 -9.708  
## Time2 0.30533 0.07516 4.062  
## Time:Smoke 0.74348 0.53306 1.395  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Time2   
## Time -0.693   
## Time2 0.690 -0.743   
## Time:Smoke -0.011 -0.365 0.012

# (b) pre-CD4 level only

model2.2.2.b <- lmer(CD4 ~ 1 + Time + Time2 + preCD4:Time + (Time-1|ID), data = BMACS)  
summary(model2.2.2.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Time2 + preCD4:Time + (Time - 1 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12749.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.9547 -0.5435 0.0054 0.5341 3.6798   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID Time 12.57 3.545   
## Residual 47.27 6.875   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 37.10536 0.43877 84.567  
## Time -10.26701 1.35066 -7.601  
## Time2 0.31054 0.07501 4.140  
## Time:preCD4 0.13210 0.02962 4.459  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Time2   
## Time -0.249   
## Time2 0.691 -0.287   
## Time:preCD4 -0.009 -0.940 0.015

# (c) both smoking status and pre-CD4

model2.2.2.c <- lmer(CD4 ~ 1 + Time + Time2 + Smoke:Time + preCD4:Time + (Time-1|ID), data = BMACS)  
summary(model2.2.2.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time + Time2 + Smoke:Time + preCD4:Time + (Time - 1 |   
## ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12748.6  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -3.9583 -0.5424 0.0043 0.5336 3.6763   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID Time 12.62 3.553   
## Residual 47.26 6.875   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 37.10292 0.43878 84.558  
## Time -10.23002 1.35483 -7.551  
## Time2 0.31084 0.07502 4.144  
## Time:Smoke 0.29614 0.53003 0.559  
## Time:preCD4 0.12888 0.03027 4.258  
##   
## Correlation of Fixed Effects:  
## (Intr) Time Time2 Tm:Smk  
## Time -0.249   
## Time2 0.690 -0.286   
## Time:Smoke -0.010 0.054 0.010   
## Time:preCD4 -0.007 -0.931 0.013 -0.196

# (d) Summary of random both

anova(model2.2.2.a,model2.2.2.b,model2.2.2.c,refit=F)

## Data: BMACS  
## Models:  
## model2.2.2.a: CD4 ~ 1 + Time + Time2 + Smoke:Time + (Time - 1 | ID)  
## model2.2.2.b: CD4 ~ 1 + Time + Time2 + preCD4:Time + (Time - 1 | ID)  
## model2.2.2.c: CD4 ~ 1 + Time + Time2 + Smoke:Time + preCD4:Time + (Time - 1 |   
## model2.2.2.c: ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.2.2.a 6 12773 12806 -6380.6 12761   
## model2.2.2.b 6 12761 12794 -6374.7 12749 11.8404 0 <2e-16 \*\*\*  
## model2.2.2.c 7 12763 12801 -6374.3 12749 0.8793 1 0.3484   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.2.3 Both random intercept and ramdom slope:

# (a) Smoking status only

model2.2.3.a <- lmer(CD4 ~ 1 + Time2 + Smoke\*Time + (1 + Time|ID), data = BMACS)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl =  
## control$checkConv, : Model failed to converge with max|grad| = 0.0022222  
## (tol = 0.002, component 1)

summary(model2.2.3.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time2 + Smoke \* Time + (1 + Time | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12118.9  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3295 -0.5443 -0.0195 0.5185 4.3035   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 77.955 8.829   
## Time 8.987 2.998 -0.32  
## Residual 24.564 4.956   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 36.2739 0.7643 47.458  
## Time2 0.3421 0.0591 5.789  
## Smoke 2.0998 1.2303 1.707  
## Time -4.6312 0.4003 -11.570  
## Smoke:Time -0.1724 0.4957 -0.348  
##   
## Correlation of Fixed Effects:  
## (Intr) Time2 Smoke Time   
## Time2 0.304   
## Smoke -0.573 -0.030   
## Time -0.500 -0.711 0.198   
## Smoke:Time 0.242 0.041 -0.443 -0.429  
## convergence code: 0  
## Model failed to converge with max|grad| = 0.0022222 (tol = 0.002, component 1)

# (b) pre-CD4 level only

model2.2.3.b <- lmer(CD4 ~ 1 + Time2 + preCD4\*Time + (1 + Time|ID), data = BMACS)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl =  
## control$checkConv, : Model failed to converge with max|grad| = 0.0554679  
## (tol = 0.002, component 1)

summary(model2.2.3.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time2 + preCD4 \* Time + (1 + Time | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12070.7  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3204 -0.5418 -0.0060 0.5281 4.3904   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 59.756 7.730   
## Time 8.804 2.967 -0.26  
## Residual 24.474 4.947   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 14.25482 2.78433 5.120  
## Time2 0.33253 0.05873 5.662  
## preCD4 0.53085 0.06350 8.360  
## Time -1.22419 1.23687 -0.990  
## preCD4:Time -0.08064 0.02756 -2.926  
##   
## Correlation of Fixed Effects:  
## (Intr) Time2 preCD4 Time   
## Time2 0.099   
## preCD4 -0.979 -0.021   
## Time -0.405 -0.258 0.382   
## preCD4:Time 0.389 0.036 -0.398 -0.957  
## convergence code: 0  
## Model failed to converge with max|grad| = 0.0554679 (tol = 0.002, component 1)

# (c) both smoking status and pre-CD4

model2.2.3.c <- lmer(CD4 ~ 1 + Time2 + Smoke\*Time + preCD4\*Time + (1 + Time|ID), data = BMACS)  
summary(model2.2.3.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Time2 + Smoke \* Time + preCD4 \* Time + (1 + Time |   
## ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12068  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3191 -0.5410 -0.0096 0.5268 4.3825   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 59.803 7.733   
## Time 8.913 2.986 -0.26  
## Residual 24.464 4.946   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 14.27936 2.78603 5.125  
## Time2 0.33173 0.05879 5.643  
## Smoke 0.59713 1.12233 0.532  
## Time -1.19910 1.24307 -0.965  
## preCD4 0.52529 0.06436 8.162  
## Smoke:Time 0.01747 0.50123 0.035  
## Time:preCD4 -0.08133 0.02811 -2.893  
##   
## Correlation of Fixed Effects:  
## (Intr) Time2 Smoke Time preCD4 Smk:Tm  
## Time2 0.099   
## Smoke 0.016 -0.031   
## Time -0.404 -0.256 0.009   
## preCD4 -0.969 -0.016 -0.160 0.375   
## Smoke:Time 0.006 0.036 -0.412 0.025 0.051   
## Time:preCD4 0.382 0.029 0.052 -0.947 -0.393 -0.170

# (d) Summary of both random

anova(model2.2.3.a,model2.2.3.b,model2.2.3.c,refit=F)

## Data: BMACS  
## Models:  
## model2.2.3.a: CD4 ~ 1 + Time2 + Smoke \* Time + (1 + Time | ID)  
## model2.2.3.b: CD4 ~ 1 + Time2 + preCD4 \* Time + (1 + Time | ID)  
## model2.2.3.c: CD4 ~ 1 + Time2 + Smoke \* Time + preCD4 \* Time + (1 + Time |   
## model2.2.3.c: ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.2.3.a 9 12137 12186 -6059.4 12119   
## model2.2.3.b 9 12089 12138 -6035.4 12071 48.133 0 <2e-16 \*\*\*  
## model2.2.3.c 11 12090 12151 -6034.0 12068 2.698 2 0.2595   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.2.4 Random intercept, random slope, and random coefficient for the second polynomial term

# (a) Smoking status only

model2.2.4.a <- lmer(CD4 ~ 1 + Smoke\*Time2 + Smoke\*Time + (1 + Time + Time2|ID), data = BMACS)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl =  
## control$checkConv, : Model failed to converge with max|grad| = 0.0105201  
## (tol = 0.002, component 1)

summary(model2.2.4.a)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Smoke \* Time2 + Smoke \* Time + (1 + Time + Time2 |   
## ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12087.9  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3769 -0.5345 -0.0335 0.5142 4.4426   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 87.0701 9.3311   
## Time 27.8373 5.2761 -0.44   
## Time2 0.4494 0.6704 0.32 -0.87  
## Residual 22.6486 4.7591   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 36.40991 0.81402 44.729  
## Smoke 1.89581 1.37245 1.381  
## Time2 0.37759 0.09173 4.116  
## Time -4.79951 0.56722 -8.461  
## Smoke:Time2 -0.02704 0.16677 -0.162  
## Smoke:Time 0.04629 0.98965 0.047  
##   
## Correlation of Fixed Effects:  
## (Intr) Smoke Time2 Time Smk:T2  
## Smoke -0.593   
## Time2 0.452 -0.268   
## Time -0.578 0.343 -0.882   
## Smoke:Time2 -0.248 0.447 -0.550 0.485   
## Smoke:Time 0.332 -0.585 0.505 -0.573 -0.875  
## convergence code: 0  
## Model failed to converge with max|grad| = 0.0105201 (tol = 0.002, component 1)

# (b) pre-CD4 level only

model2.2.4.b <- lmer(CD4 ~ 1 + preCD4\*Time2 + preCD4\*Time + (1 + Time + Time2|ID), data = BMACS)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl =  
## control$checkConv, : Model failed to converge with max|grad| = 0.0236645  
## (tol = 0.002, component 1)

summary(model2.2.4.b)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + preCD4 \* Time2 + preCD4 \* Time + (1 + Time + Time2 |   
## ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12042.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3830 -0.5321 -0.0169 0.5219 4.5209   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 64.742 8.0462   
## Time 26.690 5.1663 -0.39   
## Time2 0.439 0.6626 0.28 -0.87  
## Residual 22.590 4.7529   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 12.063110 3.097507 3.894  
## preCD4 0.584212 0.071004 8.228  
## Time2 -0.219635 0.383612 -0.573  
## Time 1.512948 2.371030 0.638  
## preCD4:Time2 0.013845 0.008896 1.556  
## preCD4:Time -0.147886 0.054580 -2.710  
##   
## Correlation of Fixed Effects:  
## (Intr) preCD4 Time2 Time pCD4:T2  
## preCD4 -0.982   
## Time2 0.455 -0.449   
## Time -0.570 0.562 -0.878   
## preCD4:Tim2 -0.444 0.456 -0.980 0.858   
## preCD4:Time 0.559 -0.572 0.864 -0.981 -0.877   
## convergence code: 0  
## Model failed to converge with max|grad| = 0.0236645 (tol = 0.002, component 1)

# (c) both smoking status and pre-CD4

model2.2.4.c <- lmer(CD4 ~ 1 + preCD4\*Time2 + preCD4\*Time + Smoke\*Time2 + Smoke\*Time + (1 + Time + Time2|ID), data = BMACS)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl =  
## control$checkConv, : Model failed to converge with max|grad| = 0.00658647  
## (tol = 0.002, component 1)

summary(model2.2.4.c)

## Linear mixed model fit by REML ['lmerMod']  
## Formula:   
## CD4 ~ 1 + preCD4 \* Time2 + preCD4 \* Time + Smoke \* Time2 + Smoke \*   
## Time + (1 + Time + Time2 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12041.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3778 -0.5342 -0.0192 0.5144 4.5095   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 65.1112 8.0691   
## Time 26.9065 5.1871 -0.40   
## Time2 0.4442 0.6665 0.29 -0.87  
## Residual 22.5861 4.7525   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 12.078803 3.104175 3.891  
## preCD4 0.581373 0.071982 8.077  
## Time2 -0.226996 0.385035 -0.590  
## Time 1.577355 2.378964 0.663  
## Smoke 0.280275 1.251307 0.224  
## preCD4:Time2 0.014435 0.009039 1.597  
## preCD4:Time -0.152426 0.055552 -2.744  
## Time2:Smoke -0.056490 0.168521 -0.335  
## Time:Smoke 0.394455 0.994042 0.397  
##   
## Correlation of Fixed Effects:  
## (Intr) preCD4 Time2 Time Smoke pCD4:T2 prCD4:T Tm2:Sm  
## preCD4 -0.972   
## Time2 0.455 -0.444   
## Time -0.570 0.555 -0.878   
## Smoke 0.009 -0.151 0.001 -0.001   
## preCD4:Tim2 -0.439 0.454 -0.971 0.851 -0.065   
## preCD4:Time 0.551 -0.569 0.855 -0.972 0.082 -0.878   
## Time2:Smoke -0.001 -0.059 0.023 -0.025 0.452 -0.157 0.142   
## Time:Smoke 0.000 0.078 -0.026 0.033 -0.575 0.147 -0.171 -0.875  
## convergence code: 0  
## Model failed to converge with max|grad| = 0.00658647 (tol = 0.002, component 1)

# (d) Summary of only random intercept

anova(model2.2.4.a,model2.2.4.b,model2.2.4.c,refit=F)

## Data: BMACS  
## Models:  
## model2.2.4.a: CD4 ~ 1 + Smoke \* Time2 + Smoke \* Time + (1 + Time + Time2 |   
## model2.2.4.a: ID)  
## model2.2.4.b: CD4 ~ 1 + preCD4 \* Time2 + preCD4 \* Time + (1 + Time + Time2 |   
## model2.2.4.b: ID)  
## model2.2.4.c: CD4 ~ 1 + preCD4 \* Time2 + preCD4 \* Time + Smoke \* Time2 + Smoke \*   
## model2.2.4.c: Time + (1 + Time + Time2 | ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.2.4.a 13 12114 12186 -6044.0 12088   
## model2.2.4.b 13 12068 12140 -6021.2 12042 45.522 0 <2e-16 \*\*\*  
## model2.2.4.c 16 12073 12162 -6020.7 12041 0.986 3 0.8046   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# 2.3 Third Task: Final Model

Compare the ﬁtness of the above models, and justify the ﬁnal chosen linear mixedeffects model for the BMACS data.

anova(model2.1.1.a,model2.1.1.b,model2.1.1.c,model2.1.2.a,model2.1.2.b,model2.1.2.c,model2.1.3.a,model2.1.3.b,model2.1.3.c,model2.2.1.a,model2.2.1.b,model2.2.1.c,model2.2.2.a,model2.2.2.b,model2.2.2.c,model2.2.3.a,model2.2.3.b,model2.2.3.c,model2.2.4.a,model2.2.4.b,model2.2.4.c,refit=F)

## Data: BMACS  
## Models:  
## model2.1.1.a: CD4 ~ 1 + Time + Smoke + (1 | ID)  
## model2.1.1.b: CD4 ~ 1 + Time + preCD4 + (1 | ID)  
## model2.1.2.a: CD4 ~ 1 + Time + Smoke + (Time - 1 | ID)  
## model2.1.2.b: CD4 ~ 1 + Time + preCD4 + (Time - 1 | ID)  
## model2.1.1.c: CD4 ~ 1 + Time + Smoke + preCD4 + (1 | ID)  
## model2.1.2.c: CD4 ~ 1 + Time + Smoke + preCD4 + (Time - 1 | ID)  
## model2.2.1.a: CD4 ~ 1 + Time + Time2 + Smoke + (1 | ID)  
## model2.2.1.b: CD4 ~ 1 + Time + Time2 + preCD4 + (1 | ID)  
## model2.2.2.a: CD4 ~ 1 + Time + Time2 + Smoke:Time + (Time - 1 | ID)  
## model2.2.2.b: CD4 ~ 1 + Time + Time2 + preCD4:Time + (Time - 1 | ID)  
## model2.1.3.a: CD4 ~ 1 + Time + Smoke + (Time | ID)  
## model2.1.3.b: CD4 ~ 1 + Time + preCD4 + (Time | ID)  
## model2.2.1.c: CD4 ~ 1 + Time + Time2 + Smoke + preCD4 + (1 | ID)  
## model2.2.2.c: CD4 ~ 1 + Time + Time2 + Smoke:Time + preCD4:Time + (Time - 1 |   
## model2.2.2.c: ID)  
## model2.1.3.c: CD4 ~ 1 + Time + Smoke + preCD4 + (Time | ID)  
## model2.2.3.a: CD4 ~ 1 + Time2 + Smoke \* Time + (1 + Time | ID)  
## model2.2.3.b: CD4 ~ 1 + Time2 + preCD4 \* Time + (1 + Time | ID)  
## model2.2.3.c: CD4 ~ 1 + Time2 + Smoke \* Time + preCD4 \* Time + (1 + Time |   
## model2.2.3.c: ID)  
## model2.2.4.a: CD4 ~ 1 + Smoke \* Time2 + Smoke \* Time + (1 + Time + Time2 |   
## model2.2.4.a: ID)  
## model2.2.4.b: CD4 ~ 1 + preCD4 \* Time2 + preCD4 \* Time + (1 + Time + Time2 |   
## model2.2.4.b: ID)  
## model2.2.4.c: CD4 ~ 1 + preCD4 \* Time2 + preCD4 \* Time + Smoke \* Time2 + Smoke \*   
## model2.2.4.c: Time + (1 + Time + Time2 | ID)  
## Df AIC BIC logLik deviance Chisq Chi Df Pr(>Chisq)   
## model2.1.1.a 5 12559 12586 -6274.4 12549   
## model2.1.1.b 5 12532 12559 -6260.8 12522 27.242 0 < 2.2e-16 \*\*\*  
## model2.1.2.a 5 12778 12806 -6384.2 12768 0.000 0 1.0000   
## model2.1.2.b 5 12588 12616 -6289.3 12578 189.929 0 < 2.2e-16 \*\*\*  
## model2.1.1.c 6 12531 12564 -6259.5 12519 59.558 1 1.187e-14 \*\*\*  
## model2.1.2.c 6 12589 12622 -6288.7 12577 0.000 0 1.0000   
## model2.2.1.a 6 12533 12566 -6260.6 12521 56.178 0 < 2.2e-16 \*\*\*  
## model2.2.1.b 6 12505 12538 -6246.6 12493 28.035 0 < 2.2e-16 \*\*\*  
## model2.2.2.a 6 12773 12806 -6380.6 12761 0.000 0 1.0000   
## model2.2.2.b 6 12761 12794 -6374.7 12749 11.840 0 < 2.2e-16 \*\*\*  
## model2.1.3.a 7 12163 12202 -6074.5 12149 600.459 1 < 2.2e-16 \*\*\*  
## model2.1.3.b 7 12117 12155 -6051.4 12103 46.284 0 < 2.2e-16 \*\*\*  
## model2.2.1.c 7 12505 12543 -6245.3 12491 0.000 0 1.0000   
## model2.2.2.c 7 12763 12801 -6374.3 12749 0.000 0 1.0000   
## model2.1.3.c 8 12116 12160 -6050.2 12100 648.156 1 < 2.2e-16 \*\*\*  
## model2.2.3.a 9 12137 12186 -6059.4 12119 0.000 1 1.0000   
## model2.2.3.b 9 12089 12138 -6035.4 12071 48.133 0 < 2.2e-16 \*\*\*  
## model2.2.3.c 11 12090 12151 -6034.0 12068 2.698 2 0.2595   
## model2.2.4.a 13 12114 12186 -6044.0 12088 0.000 2 1.0000   
## model2.2.4.b 13 12068 12140 -6021.2 12042 45.522 0 < 2.2e-16 \*\*\*  
## model2.2.4.c 16 12073 12162 -6020.7 12041 0.986 3 0.8046   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

model2.2.4.b had the lowest AIC and the second lowest BIC, so it was the best model.

# 3. Estimates and inferences of the best model

modelfinal=lmer(CD4~1+Smoke+Time+Smoke:Time+Time2+Smoke:Time2+(1+Time+Time2|ID),data=BMACS)  
summary(modelfinal)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: CD4 ~ 1 + Smoke + Time + Smoke:Time + Time2 + Smoke:Time2 + (1 +   
## Time + Time2 | ID)  
## Data: BMACS  
##   
## REML criterion at convergence: 12087.9  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.3769 -0.5344 -0.0335 0.5142 4.4425   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 87.0574 9.3305   
## Time 27.8274 5.2752 -0.44   
## Time2 0.4491 0.6701 0.32 -0.87  
## Residual 22.6498 4.7592   
## Number of obs: 1817, groups: ID, 283  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 36.40991 0.81397 44.731  
## Smoke 1.89572 1.37237 1.381  
## Time -4.79952 0.56716 -8.462  
## Time2 0.37760 0.09172 4.117  
## Smoke:Time 0.04643 0.98954 0.047  
## Smoke:Time2 -0.02708 0.16675 -0.162  
##   
## Correlation of Fixed Effects:  
## (Intr) Smoke Time Time2 Smk:Tm  
## Smoke -0.593   
## Time -0.578 0.343   
## Time2 0.452 -0.268 -0.882   
## Smoke:Time 0.332 -0.585 -0.573 0.505   
## Smoke:Time2 -0.248 0.447 0.485 -0.550 -0.875