The correct depth to place nasogastric tubes; the NPSA guideline is incorrect.

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Abstract

A tube length measured from nose to ear to xiphisternum (NEX) is advised for nasogastric tube (NGT) placement. Because the xiphisternum is more difficult to locate and NEX only approximates to the distance at the gastro-oesophageal junction (GOJ) local policy is to measure in the opposite direction (XEN) then add 10cm.

XEN averaged 48cm in 36 critically ill patients age 51±20y. Using an electromagnetic (EM) trace to note anatomical position we measured the mean insertion distance from tube marking at: a) Pre-gastro-oesophageal junction (GOJ) (48cm), where the tube first turns left towards the stomach and becomes shallow on the trace; b) Gastric body (63cm), where the tube reaches the left-most part of the stomach; and c) Gastric antrum (73cm) at the midline on the EM trace. Using body length, age, sex and XEN in a linear regression model, only 40% of variability was predicted, showing that external measurements cannot reliably predict the length of tube required to reach the stomach.

A tube length of XEN (or NEX) is too short to guarantee gastric placement and is therefore unsafe. XEN + 10cm or more complex measurements will reach the gastric body (mid-stomach) in most patients. However, only the EM trace or direct vision showed in real-time whether the tip has safely reached the gastric body.

Key words

Cortrak, misplacement, nasogastric tube, nose-ear-xiphisternum (NEX).

Key phrases

Placing NG tubes is vital for patients requiring artificial nutritional support, but potentially dangerous. Inserting the correct tube length is a pre-requisite to safely confirming position. Practitioners require an accurate guide to gastric placement length. The nose-ear-xiphisternum (NEX) measurement is both impractical and too short. NEX should be replaced by xiphisternum-ear-nose (XEN) + at least 10cm. However, accurate tip placement is only possible with direct vision or EM tracing.

Conflict of interest

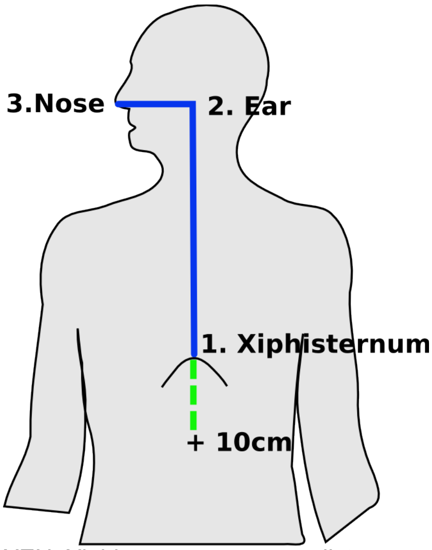
Stephen Taylor served on a Corpak consultation committee once in 2007 and completed an unrelated Corpak-funded audit in 2013.

Introduction

Feeding tube misplacement is a potentially fatal and underestimated problem. Each year the United Kingdom (UK) National Health Service uses about 271,000 tubes [NPSA, 2008]; 20 undetected, misplaced tubes are used for feeding and cause serious harm ('NEVER' events), including 4 deaths [NPSA, 2011b]. This is probably an underestimate because a systematic review found 1.9% of 9931 feeding tubes ≤12FG were misplaced [Sparks et al, 2011]. A similar rate in the UK would equate to 5149 misplacements, 963 pneumothoraces and 218 deaths per year [Taylor, 2013].

Confirmation of gastric position is key to detecting misplacement, albeit after trauma may have occurred. UK National Patient Safety Association (NPSA) recommend pH and X-ray for first and second-line confirmation, respectively. To ensure enough tube is inserted to reach the stomach, but not an excess that might cause kinking and blockage, NPSA advise estimating the required length by measuring from nose-ear-xiphoid process (or xiphisternum) [NPSA, 2011]. In contrast, local policy is to measure the xiphisternum-ear-nose (XEN, pronounced 'ZEN') distance and add 10cm because: a) It is more practical and accurate to locate the most difficult anatomical point first, and b) XEN approximates the distance from nose to gastro-oesophageal junction GOJ and is therefore insufficient to ensure gastric placement (Figure 1). Placing a tube to the XEN distance risks feeding into the oesophagus and consequent aspiration. Even where the tube is initially confirmed as gastric, minor slippage risks displacement into the oesophagus. In addition, multi-port tubes may be confirmed as 'gastric' when gastric juice is aspirated from the distal ports but feed may enter the oesophagus from the more proximal ports, outside the stomach.

Figure 1: Estimation of NG tube distance: 'XEN + 10' [Taylor, 2014].

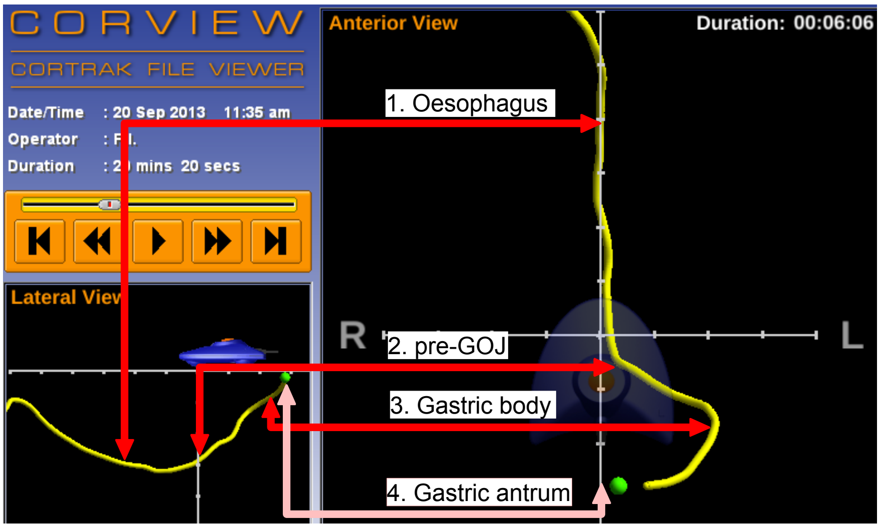


XEN: Xiphisternum-ear-nose distance.

We audited the length of tube inserted against XEN and gastric position in intensive care unit (ICU) patients requiring routine NG tube placement or when the patient had delayed gastric emptying, nasointestinal (NI) tube placement.

Methods

In ICU patients requiring placement of NG or NI tubes XEN was measured using the tube or a tape (Figure 1). Tube placement was guided using an EM trace, using a previously published technique [Taylor et al, 2010], in conjunction with Cortrak™ tubes (NG: 92cm, 12FG, NI: 140cm, 10FG). The tube has safely entered the oesophagus (Figure 2: point 1.) as seen by a vertical anterior trace; significant left or right deviation above the horizontal line would indicate possible lung misplacement. The 'lateral' or 'cross-section' screens show increased depth in the oesophagus. Tube distance was noted at anatomical points that approximate specific patterns on the EM trace (Figure 2):



2. Pre-GOJ: Just prior to the GOJ, the trace deflects left and from deep to shallow as it moves from oesophagus to stomach.

3. Gastric body: The trace becomes increasingly shallow and is at the left-most position (3 O'clock) before deflecting right, towards the antrum and pylorus.

4. Gastric antrum: The trace reaches the midline, approximating the shallowest point on the trace before it again goes deeper and moves to the right in an anti-clockwise circle around the duodenum.

Measurements were noted in 'cm'. Statistically each series was tested for normal distribution using the Sharpiro-Wilk test. Differences between the length to the gastric body and measurements were tested using paired t-test or Wilcox rank sum test as appropriate. Distances were analysed using linear regression for statistical difference and interaction with patient age, height (measured or reported) and weight (reported or estimated). Confirmation that the tube had attained at least gastric position was done by X-ray, pH $\leq$5.0 or a subsequent intestinal EM trace.

Results

Measurements were undertaken on 36 ICU patients. Because Frenchay hospital is a trauma centre patients were disproportionately male and, for an ICU population, relatively young (Table 1), reflecting a large neurosurgery and trauma populations (Table 2). Most patients were sedated or unconscious and/ or had an artificial airway and are therefore considered 'high risk' for placement of feeding tubes [Taylor, 2013]. Tube distance at pre-GOJ was only 2cm short of XEN (Figure 3). However, compared to the distance to the gastric body XEN was significantly shorter (-13.8cm, 95% confidence interval: -15.4, -12.1; p<0.0001); XEN+10cm was close but still too short (-3.8cm, 95% confidence interval: -5.4, -2.1; p<0.0001). All except one tube was confirmed to be in the stomach by other methods (X-ray: 64%; pH ≤5.0: 29%: subsequent intestinal EM trace: 64%; all methods: 98%).

Table 1: Patient demography and measurements.

Parameter	**Mean**	**SD**	**Min**	**Max**
Sex (male)	81%	.	.	.
age	51.06	19.93	17	82
cm	171.2	9.08	148	186
kg	80.11	18.63	49.4	140

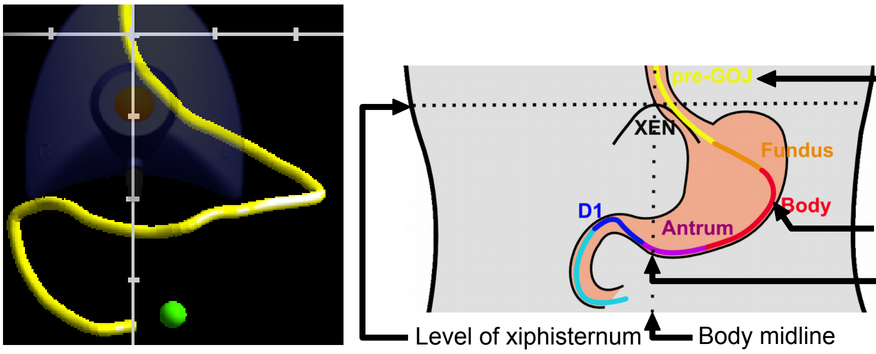
Table 2: Patient state.

Variable	**Category**	**n**	**%**
Disease	Medical	12	33.1
	Neurosurgical (non-trauma)	4	11.1
	Surgery (general)	9	25.2
	Trauma	11	30.6
Conscious state	Awake	13	36.1
	Sedated	18	50
	Unconscious	5	13.9
Airway	Endotracheal	17	47.2
	Normal	4	11.1
	Tracheostomy	15	41.7

Table 3

Description	Mean	SD	Min	Max
*Deviation to L + deep to shallow	48.2	3.2	42.0	61.0
Measure Xiphisternum to ear to nose	50.7	4.0	40.0	59.0
*L-most position of gastric curve	62.3	5.7	46.0	82.0
*Midline at the bottom of the stomach	73.4	7.0	52.0	97.0

Figure 3 Gastric EM trace, anatomy, description of related EM trace and distance from the nose (cm).



Description	Mean	SD	Min	Max
*Deviation to L + deep to shallow	48.2	3.2	42.0	61.0
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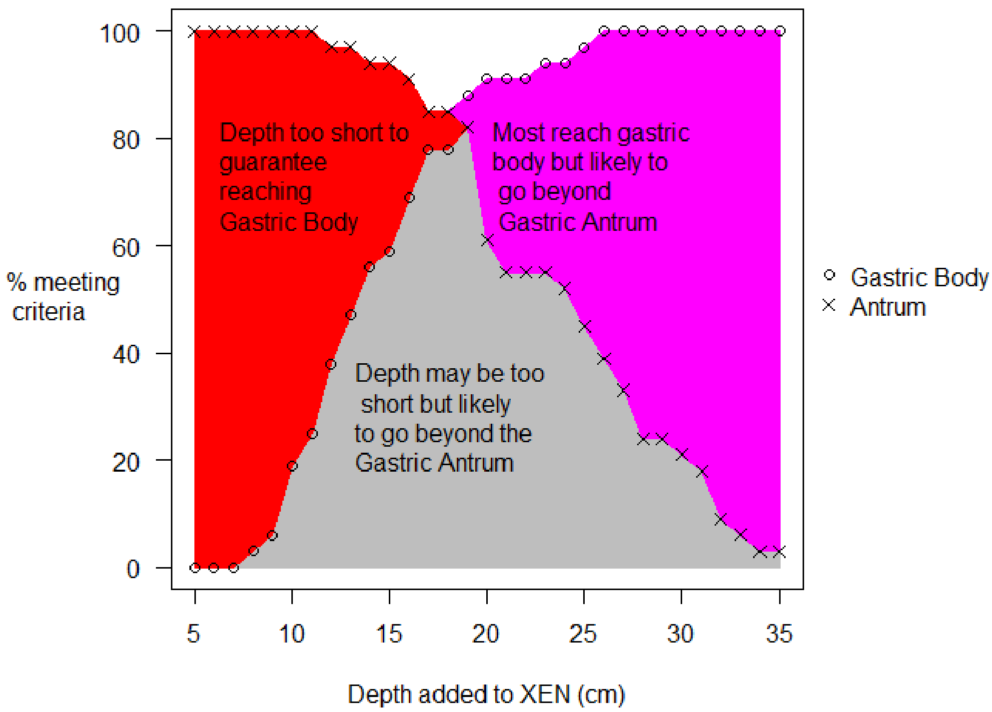
*Midline at the bottom of the stomach	73.4	7.0	52.0	97.0

Linear regression showed that depth to gastric body = 0.6*XEN + 34.4cm but only predicted 27.5% of variability. In a more complex model depth to gastric body = 0.36*XEN + 0.01*Age (years) + 0.23 * height (cm) – 0.6*sex (if male) + 4.4cm predicted 40% of variability. Weight (kg) made little difference possibly because this often had to be estimated rather than measured. Adding interactions between XEN and age, height and sex improved prediction of variability to 55%. However external measurements (age, height, sex, weight) only explain 6% of the difference between XEN and depth to gastric body and none were significantly associated. Lastly, we plotted the percentage of tubes reaching the gastric body but being less than the depth at the midline (antrum) against the distance added to XEN (Figure 4). While XEN + 18cm is the optimal distance, nearly 20% of tubes either fail to reach the gastric body or exceed the distance to the midline and risk oesophageal or intestinal placement, respectively.

Figure 4 Depth added to XEN to reach the gastric body or antrum.



Discussion

XEN and tube distance to the GOJ were clinically similar as were XEN + 10cm and distance to the gastric body. However, XEN and the distance to the gastric body were significantly clinically and statistically different. This means that when a tube is placed to a distance equalling XEN and minor adjustments during insertion succeed in obtaining gastric juice with a pH confirming gastric position, the tube will be only just within the stomach. The same will happen if the tube tip is noted on X-ray to be below the diaphragm but only just within the stomach if staff fail to significantly advance the tube. Alternatively, if the tube is in the oesophagus, pH will fail to confirm tube position and result in an unnecessary X-ray.

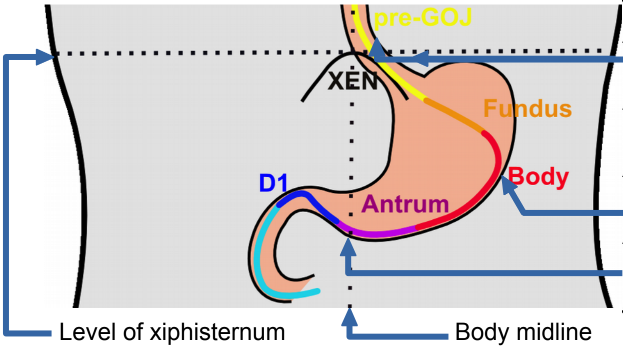
Audits show that of the tubes found within the oesophagus, ≤10% were coiled or looped, showing that most fail to reach the stomach because insufficient length is inserted [Rayner, 2012; 2013]. However, after staff reminders to insert XEN+10cm, X-ray findings of tubes in the distal oesophagus dropped from 16% to 7% [Rayner, 2012; 2013]; there were a similar number close to the GOJ (2.5% vs 3.2%, respectively). Placing insufficient tube needlessly necessitated further tube advancement, patient risk and discomfort, irradiation and cost (£37.50 per X-ray, excluding staff time). Facilitating gastric confirmation by placing the correct length of tube from the outset can reduce discomfort, staff time and X-ray cost. XEN (or NEX, NPSA, 2011) is too short. To reach the gastric body requires XEN plus an average of another 14cm; 18cm is optimal for reaching the gastric body, but may go beyond the antrum. 'XEN + 10cm' is clinically close to this distance and easy to remember.

A criticism of this study is the small sample size. In addition, most of the patients with NI tubes had delayed gastric emptying, possibly with some distension and therefore may have longer gastric body distances. Larger studies are required to confirm distances and the effect of patient demographics and conditions such as delayed gastric empting. In addition, EM traces do not show actual anatomy, for example, the z-line, demarcating oesophagus from stomach. However, all except one tube was confirmed to be in the stomach by other methods (X-ray: 64%; pH ≤5.0: 29%: subsequent intestinal EM trace: 64%; all methods: 98%). Finally the EM trace shows where the tube tip has been, not where the tube lies. Thus there might be slack tube behind the tip, exaggerating the distance it takes to reach the gastric body. However, 'slack coiling' is uncommon until the tip reaches the antrum and particularly superior duodenal flexure.

Misplacement of feeding tubes can result in major complications. The procedure can be uncomfortable for the patient, time-consuming for staff and costly in healthcare. Even allowing for some patients in this study suffering distension, based on these preliminary findings, when placing NG feeding or drainage tubes, XEN (or NEX) is inadequate and unsafe and should instead be at least XEN + 10cm. An EM trace permits real-time adjustment and confirmation of position.

References

NPSA, 2008	NPSA (2008) Incidents related to nasogastric tubes. In: Quarterly Data Report. www.npsa.nhs.uk/nrls/patient-safety-data/quarterly-data-reports.
NPSA, 2011	NPSA (2011) Patient Safety Alert NPSA/2011/PSA002: Reducing the harm caused by misplaced nasogastric feeding tubes in adults, children and infants. Supporting Information.
Sparks et al, 2011	Sparks DA, Chase DM, Coughlin LM, Perry E (2011) Pulmonary Complications of 9931 Narrow-Bore Nasoenteric Tubes During Blind Placement: A Critical Review. J Parent Ent Nutr. 35:625-9.
Taylor, 2013	Taylor SJ (2013) Confirming nasogastric feeding tube position versus the need to feed. Intens Crit Care Nurs. 29: 59-69.
Taylor, 2014	Taylor SJ (2014) Cortrak tube placement: Advanced training. Silhouette Publications.
Taylor et al, 2010	Taylor, S, Manara A, Brown J (2010) Nasointestinal placement versus prokinetic use when treating delayed gastric emptying in ICU patients. Br J Intens Care. 20:38-44.
Rayner, 2012	Rayner W (2012) Placement of fine bore nasogastric feeding tubes - re-audit. Radiology Dept. Frenchay Hospital. North Bristol NHS Trust.
Rayner, 2013	Rayner W (2013) Placement of fine bore nasogastric feeding tubes - re-audit. Radiology Dept. Frenchay Hospital. North Bristol NHS Trust.



Description (Cortrak*)	cm from nose
*Deviation to L + deep to shallow	48
Measure: Xiphisternum to ear to nose	50
*L-most position of the gastric curve	63
*Midline at the bottom of the stomach	73

1

Summary Statistics: Categorical Variables

d_categ	Percentage	Count
medical	33.11	12
Neurosurgical (non-trauma)	11.11	4
surgery (general)	25	9
trauma	30.56	11

sex	Percentage	Count
0	19.44	7
1	80.57	29

awake	Percentage	Count
a	36.11	13
s	50	18
u	13.89	5

airway	Percentage	Count
e	47.22	17
n	11.11	4
t	41.67	15

note "none" has been re-coded from 0 to n

Route	Percentage	Count
NG	38.89	14
NI	61.11	22

Summary Statistics: Continuous Variables

Variable	Min	1st	Med	Mean	3rd	Max	Missing	Std Dev	Std Error	Coeff of Variation
age	17	37.25	52.5	51.06	69	82	0	19.933	3.322	0.390
cm	148	168.2	171.5	171.2	179	186	0	9.083	1.514	0.053
kg	49.4	70	76	80.11	83.95	140	0	18.632	3.105	0.233
depth_xen	40	48	49.5	49.75	52	58	0	4.232	0.705	0.085
depth_goj	42	46	47	48.03	50	55	0	3.038	0.506	0.063
depth_f	45	53	55	55.48	58	64	3	4.017	0.070	0.072
depth_b	51	60	65	63.41	66.25	76	4	4.885	0.864	0.077
depth_mid	62	68	73	72.91	75	90	3	6.171	1.074	0.085
xen&10cm	50	58	59.5	59.75	62	68	0	4.232	0.705	0.071
depth_b.xen	7	10.75	13	13.78	16	25	4	4.542	0.080	0.330

1st : represents 1st Quartile
Med: represents the median
3rd: represents 3rd Quartile
Std Dev: standard deviation
Std Error: standard error
Coeff of Variation: coefficient of variation (standard deviation/mean)

Further Tests

Shapiro Wilk's test of normality was then performed on the depth variables; as all of the p-values were in excess of .05, they were deemed to be sufficiently normally distributed to use the paired t-test to compare the relative depths.

depth_goj was found to be statistically significantly smaller than depth_xen
depth_xen was found to be statistically significantly smaller than depth_f and depth_b
Adding 10 to depth_xen would still result in it being statistically significantly smaller than depth_b, but it becomes statistically significantly larger than depth_f.

Further models can be produced to model the relationship between the depth measurements, taking into account the other covariates present (such as age, sex, weight and height, and the other categorical variables); however coefficient estimates for a very complex model, incorporating interactions, results in values that are numerically unstable [insufficient data on which to accurately estimate values].

Code used

```
setwd("H:\\") # changes working directory
Data<-read.csv("StephensData-analysisformat.csv",header=TRUE)
# loads up dataset
attach(Data) # attaches data for convenience

names(Data) # lists variable names
sex<-as.factor(sex) # turns sex variable into a category variable
## percentages in each category.
100*summary(d_categ)/36
100*summary(sex)/36
100*summary(awake)/36
100*summary(airway)/36
100*summary(Route)/36
## counts in each category
summary(d_categ)
summary(sex)
summary(awake)
summary(airway)
summary(Route)

# descriptive statistics for continuous variables
# write my own function to include the standard summary and then also
# the standard devation, standard error and coefficient of variation

mySummary<-function(x,roundto=8){
N<-sum(!is.na(x))
if(N==length(x)){
xsum<-c(summary(x),sd(x,na.rm=TRUE),sd(x,na.rm=TRUE)/sqrt(N),sd(x,na.rm=TRUE)/mean(x,na.rm=TRUE))
names(xsum)<-c(names(xsum)[1:6],"St Dev","St Error","Coef of Var")
}
if(N!=length(x)){
xsum<-c(summary(x),sd(x,na.rm=TRUE),sd(x,na.rm=TRUE)/sqrt(N),sd(x,na.rm=TRUE)/mean(x,na.rm=TRUE))
names(xsum)<-c(names(xsum)[1:7],"St Dev","St Error","Coef of Var") # allows for extra column for
# number of missing values
}
round(xsum,roundto)
}## end of custom function
```

Code Used Continued

```
# producing the descriptive statistics
mySummary(age,roundto=3)
mySummary(cm,roundto=3)
mySummary(kg,roundto=3)
mySummary(depth_xen,roundto=3)
mySummary(depth_goj,roundto=3)
mySummary(depth_f,roundto=3)
mySummary(depth_b,roundto=3)
mySummary(depth_mid,roundto=3)
mySummary(xen_and_10cm,roundto=3)
mySummary(depth_b.xen,roundto=3)
shapiro.test(depth_xen)
shapiro.test(depth_goj)
shapiro.test(depth_f)
shapiro.test(depth_b)
shapiro.test(depth_mid)
shapiro.test(xen_and_10cm)
shapiro.test(depth_b.xen)
## if they failed normality tests....

wilcox.test(depth_xen,depth_goj)
wilcox.test(depth_xen,depth_f)
wilcox.test(depth_xen,depth_b)

## these give warning messages about not being able to compute exact pvalues with ties
## this is okay!

wilcox.test(xen_and_10cm,depth_f)
wilcox.test(xen_and_10cm,depth_b)


## but they haven't..
t.test(depth_xen,depth_goj,paired=TRUE)
t.test(depth_xen,depth_f,paired=TRUE)
t.test(depth_xen,depth_b,paired=TRUE)

t.test(xen_and_10cm,depth_f,paired=TRUE)
t.test(xen_and_10cm,depth_b,paired=TRUE)

t.test(depth_xen+6,depth_f,paired=TRUE)
t.test(depth_xen+14,depth_b,paired=TRUE)
```

Code Used Continued (for more complex linear model)

```
## trying to build a more complex model....

mod1<-lm(depth_b~depth_xen+kg+sex+age+Route+d_categ+awake+airway+cm)
summary(mod1)
mod2<-step(mod1,scope=.~.^2) # considers main effects and 2 way interactions with all
# explanatory variables, using AIC for model selection.
summary(mod2)
mod3<-update(mod2,.~.-d_categ:awake) # because of unobserved combinations!
summary(mod3)
mod4<-step(mod3) # can the model be simplified?
summary(mod4)

par(mfrow=c(2,2)) # creates a 2 by 2 plotting grid
plot(mod4) # draws the diagnostic plots for the model named “mod4”

mod5<-lm(depth_f~depth_xen+kg+sex+age+Route+d_categ+awake+airway+cm)
summary(mod5)
mod6<-step(mod5,scope=.~.^2)
summary(mod6)
mod7<-update(mod6,.~.-awake:airway-d_categ:airway)
# because of unobserved combinations!
summary(mod7)
mod8<-step(mod7) # can the model be simplified?
summary(mod8)
```

```
par(mfrow=c(2,2))  # creates a 2 by 2 plotting grid
plot(mod4) # draws the diagnostic plots for the model named "mod4"
```

Table 1.1: Patient demography and measurements.

Variable	Parameter	**Mean**	**SD**	**Min**	**Max**
Demography	Sex (male)	81%	.	.	.
	age	51.06	19.933	17	82
	cm	171.2	9.083	148	186
	kg	80.11	18.632	49.4	140
Tube depth	GOJ	48.03	3.038	42	55
	XEN	49.75	4.232	40	58
	Fundus	55.48	4.017	45	64
	Body	63.41	4.885	51	76
	Antrum	72.91	6.171	62	90
	xen&10cm	59.75	4.232	50	68
	depth_b.xen	13.78	4.542	7	25

Position	**Description (Cortrak*)**	**Mean**	**SD**	**Min**	**Max**
pre-GOJ	*Deviation to L + deep to shallow	48.03	3.04	42	55
XEN	Measure: Xiphisternum to ear to nose	49.75	4.23	40	58
Body	*L-most position of the gastric curve	63.41	4.89	51	76
Antrum	*Midline at the bottom of the stomach	72.91	6.17	62	90

Position	**Description (Cortrak*)**	**cm from nose**
pre-GOJ	*Deviation to L + deep to shallow	48
XEN	Measure: Xiphisternum to ear to nose	50

Position	Description (Cortrak*)	cm from nose
Body	*L-most position of the gastric curve	63
Antrum	*Midline at the bottom of the stomach	73

Cuts

young (33% medical, 11% neurosurgical [non-trauma], 25% surgical, 31% trauma) of which 81% were male. Most were ventilated and had an artificial airway (47% endotracheal tube, 42% tracheostomy) and were either sedated (50%) or unconscious (14%). Each patient had an NG (39%) or NI (61%) tube placed. Patients were 51±20y old, 168±9cm (measured or reported height) and 80±19kg .

2 Model analysis

diff_f is depth_f-depth_xen

Call:
lm(formula = diff_f ~ kg + sex + age + Route + d_categ + awake + airway + cm + depth_goj + age:awake + kg:age + cm:depth_goj + awake:cm + Route:d_categ + kg:d_categ)

Residuals:

Min	1Q	Median	3Q	Max
-0.7261	-0.1290	0.0000	0.1748	0.6252

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	720.4958	116.0302	6.209552	0.000441
kg	0.753557	0.102305	7.36575	0.000154
sex=1	10.37151	2.347468	4.41817	0.003088
age	0.915086	0.118007	7.754497	0.000111
NI	-8.98412	2.138038	-4.20204	0.004025
neuro	14.04887	7.316939	1.920048	0.096323
surgery	8.27253	3.320411	2.491418	0.04151
trauma	9.270284	4.321301	2.145253	0.069096
awake s	54.63389	9.795852	5.577248	0.000836
awake u	-150.325	42.69627	-3.52079	0.009717
airway n	0.975676	1.004977	0.970845	0.363968
airway t	1.240915	0.763787	1.624688	0.148257
cm	-4.55923	0.694838	-6.56157	0.000315
depth_goj	-14.0843	2.268076	-6.20979	0.000441
age:awake s	-0.42647	0.043841	-9.72766	2.57E-05
age:awake u	-0.03166	0.071725	-0.44136	0.672264
kg:age	-0.01037	0.001439	-7.20655	0.000176
cm:depth_goj	0.081138	0.012797	6.340653	0.000389
awake s:cm	-0.13046	0.051205	-2.54789	0.038221
awake u:cm	0.931175	0.237331	3.923534	0.005723
NI: neuro	9.099045	2.316223	3.928399	0.005687
NI: surgery	7.060008	2.374813	2.972869	0.020723
NI: trauma	6.650424	2.873393	2.314484	0.05383
kg: neuro	-0.34385	0.116971	-2.9396	0.021725
kg: surgery	-0.11135	0.05033	-2.21244	0.062572
kg:trauma	-0.25746	0.073494	-3.50312	0.009951

Residual standard error: 0.7062 on 7 degrees of freedom
(3 observations deleted due to missingness)
Multiple R-squared: 0.9862, Adjusted R-squared: 0.9371 [this is extremely high!]
F-statistic: 20.08 on 25 and 7 DF, p-value: 0.0002214

Data with predicted values:

							depth				Difference	
d_categ	**age**	**sex**	**cm**	**kg**	**awake**	**airway**	**xen**	**goj**	**f**	**Route**	**Fitted**	**Actual**
trauma	19	1	184	75	s	e	52	52	60	NG	7.53	8
trauma	61	1	172	65	s	t	55	52	58	NG	3.64	3
medical	40	1	169	70	u	t	55	50	64	NG	9.10	9
trauma	41	0	158	80	s	e	40	47	50	NG	9.71	10
trauma	24	1	161	76	a	t	51	46	52	NG	1.13	1
trauma	73	1	160	68	u	t	43	44	52	NG	8.83	9
medical	60	1	180	83.6	a	n	57	54	62	NG	5.19	5
neuro	30	1	175	73	s	e	49	46	55	NG	6.00	6
medical	60	0	161	82	a	t	49	48	54	NG	4.37	5
trauma	38	1	178	68	s	e	58	50	62	NG	3.43	4
trauma	24	1	181	80	s	e	51	47	56	NG	5.73	5
surgery	82	1	170	76	a	t	48	50	58	NG	10.00	10
medical	45	0	166	77	a	t	43	42	45	NG	2.34	2
neuro	74	0	148	59	a	t	45	48	53	NG	8.00	8
surgery	82	1	170	76	a	t	48	50	56	NI	8.08	8
medical	69	1	173	140	s	e	56	46	58	NI	2.07	2
neuro	30	1	175	73	s	e	49	45	55	NI	6.00	6
medical	75	1	169	68	s	t	48	45	52	NI	3.47	4
surgery	82	1	170	76	a	t	48	50	56	NI	8.08	8
trauma	43	1	179	89	u	e	50	48	52	NI	1.61	2
surgery	73	0	164	49.4	a	t	45	47	50	NI	4.96	5
medical	47	1	180	107	s	e	42	46	50	NI	7.77	8
surgery	59	1	171	70	a	t	52	52	56	NI	4.05	4
medical	17	1	179	70	s	e	52	46	58	NI	5.99	6
surgery	46	1	171	93	a	n	49	50	55	NI	5.54	6
medical	76	0	156	62	s	e	49	45	54	NI	5.35	5
trauma	35	1	180	102	s	e	50	50	55	NI	5.01	5
surgery	53	1	180	73	s	e	52	47	57	NI	4.83	5
trauma	21	1	186	85	s	e	55	46	55	NI	0.42	0
surgery	55	1	174	90	u	e	50	53	62	NI	12.46	12
medical	62	0	152	80	a	n	49	45	55	NI	6.27	6
medical	69	1	173	140	s	e	56	46	58	NI	2.07	2
trauma	20	1	183	78	s	t	50	50	56	NI	5.96	6

Notes:
d_categ
surgery – surgery (general)
neuro –Neurosurgical (non-trauma)
airway: n corresponds to none
Baseline categories: d_categ: medical; sex: 0; awake: a; airway: e; Route: NG

Example of interaction effect: Using patient 1 – No1 represents the actual patient (first column represents values, second represents values*coefficient); subsequent columns illustrate the effect of altering age, then weight, then age and weight on the fitted value [estimated value of the difference between depth_f and depth_xen

	Coeff	No1		No1 @ 42 years		No1 @ 85kg		No1 @ 42yrs and 85kg	
(Intercept)	720.5	1	720.5	1	720.5	1	720.5	1	720.5

kg	0.8	75	56.5	75	56.5	85	64.1	85	64.1
sex=1	10.4	1	10.4	1	10.4	1	10.4	1	10.4
age	0.9	19	17.4	42	38.4	19	17.4	42	38.4
NI	-9.0	0	0.0	0	0	0	0	0	0
neuro	14.0	0	0.0	0	0	0	0	0	0
surgery	8.3	0	0.0	0	0	0	0	0	0
trauma	9.3	1	9.3	1	9.3	1	9.3	1	9.3
awake s	54.6	1	54.6	1	54.6	1	54.6	1	54.6
awake u	-150.3	0	0.0	0	0	0	0	0	0
airway n	1.0	0	0.0	0	0	0	0	0	0
airway t	1.2	0	0.0	0	0	0	0	0	0
cm	-4.6	184	-838.9	184	-838.9	184	-838.9	184	-838.9
depth_goj	-14.1	52	-732.4	52	-732.4	52	-732.4	52	-732.4
age:awake s	-0.4	19	-8.1	42	-17.9	19	-8.1	42	-17.9
age:awake u	0.0	0	0.0	0	0	0	0	0	0
kg:age	0.0	1425	-14.8	3150	-32.7	1615	-16.7	3570	-37
cm:depth_goj	0.1	9568	776.3	9568	776.3	9568	776.3	9568	776.3
awake s:cm	-0.1	184	-24.0	184	-24	184	-24	184	-24
awake u:cm	0.9	0	0.0	0	0	0	0	0	0
NI: neuro	9.1	0	0.0	0	0	0	0	0	0
NI: surgery	7.1	0	0.0	0	0	0	0	0	0
NI: trauma	6.7	0	0.0	0	0	0	0	0	0
kg: neuro	-0.3	0	0.0	0	0	0	0	0	0
kg: surgery	-0.1	0	0.0	0	0	0	0	0	0
kg: trauma	-0.3	75	-19.3	75	-19.3	85	-21.9	85	-21.9
Fitted Value			7.5		0.9		10.5		1.5

diff_b is depth_b-depth_xen
Call:
lm(formula = diff_b ~ kg + age + Route + d_categ + awake + kg:age)

Residuals:
   Min   1Q Median   3Q   Max
-6.604 -2.253 -0.496 1.458 9.303

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-22.2826	19.28564	-1.1554	0.260321
kg	0.470702	0.25283	1.861737	0.076054
age	0.582256	0.29153	1.997242	0.058315
NI	-3.56184	2.04451	-1.74215	0.095448
neuro	-1.54097	2.775408	-0.55522	0.584345
surgery	3.450621	2.446034	1.4107	0.172317
trauma	-4.53223	2.639713	-1.71694	0.100038
awake s	6.535671	2.223228	2.939722	0.00758
awake u	8.195494	3.115666	2.630415	0.015278
kg : age	-0.00799	0.003813	-2.09644	0.047763

Residual standard error: 4.174 on 22 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared: 0.4006,   Adjusted R-squared: 0.1555 [In comparison to the previous example, this is very poor]
F-statistic: 1.634 on 9 and 22 DF, p-value: 0.1666

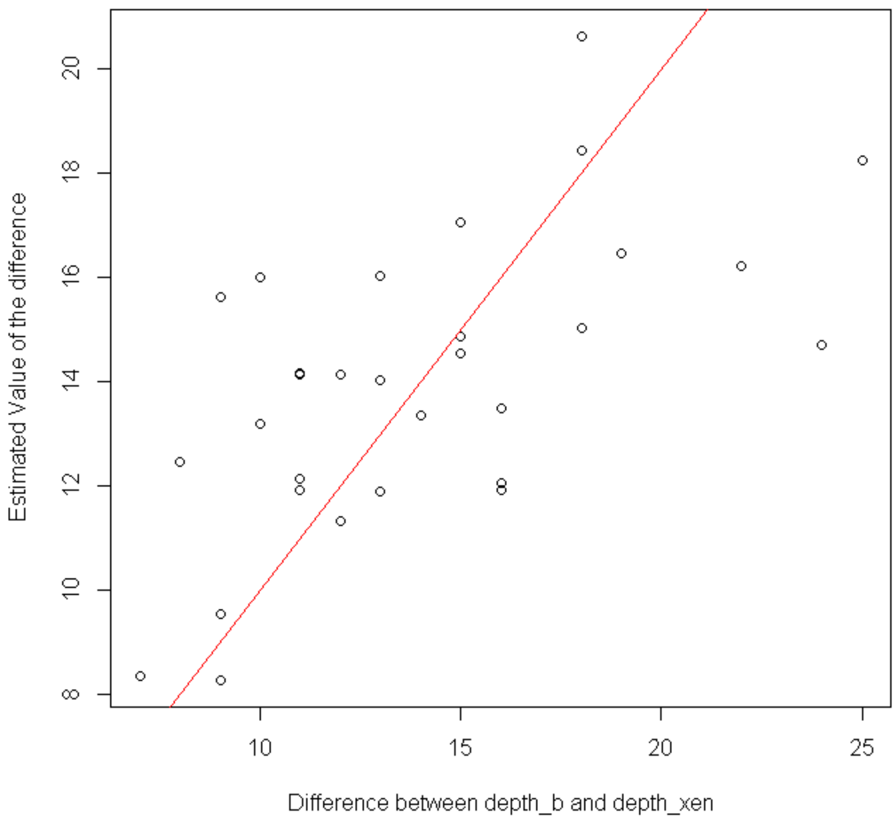
Data with predicted values:

							Depth				Difference	
d_categ	age	se x	cm	kg	awake	airway	xen	goj	b	Route	Fitted	Actual
trauma	19	1	184	75	s	e	52	52	76	NG	14.696	24
trauma	61	1	172	65	s	t	55	52	66	NG	14.142	11
trauma	41	0	158	80	s	e	40	47	58	NG	15.033	18
trauma	24	1	161	76	a	t	51	46	58	NG	8.354	7
trauma	73	1	160	68	u	t	43	44	65	NG	16.216	22
medical	60	1	180	83.6	a	n	57	54	68	NG	11.911	11
neuro	30	1	175	73	s	e	49	46	64	NG	17.037	15
medical	60	0	161	82	a	t	49	48	65	NG	11.925	16
trauma	38	1	178	68	s	e	58	50	68	NG	13.201	10
trauma	24	1	181	80	s	e	51	47	61	NG	16.005	10
surgery	82	1	170	76	a	t	48	50	63	NG	14.875	15
medical	45	0	166	77	a	t	43	42	51	NG	12.468	8
neuro	74	0	148	59	a	t	45	48	56	NG	12.138	11
surgery	82	1	170	76	a	t	48	50	60	NI	11.313	12
medical	69	1	173	140	s	e	56	46	65	NI	9.554	9
neuro	30	1	175	73	s	e	49	45	65	NI	13.475	16
medical	75	1	169	68	s	t	48	45	57	NI	15.604	9
surgery	82	1	170	76	a	t	48	50	60	NI	11.313	12
neuro	55	1	170	70	s	e	46	46	60	NI	13.351	14
trauma	43	1	179	89	u	e	50	48	61	NI	14.160	11
surgery	73	0	164	49.4	a	t	45	47	60	NI	14.540	15
medical	47	1	180	107	s	e	42	46	67	NI	18.226	25
surgery	59	1	171	70	a	t	52	52	65	NI	11.898	13
medical	17	1	179	70	s	e	52	46	65	NI	14.027	13
medical	76	0	156	62	s	e	49	45	68	NI	16.464	19
trauma	35	1	180	102	s	e	50	50	63	NI	16.015	13
surgery	53	1	180	73	s	e	52	47	70	NI	18.438	18
trauma	21	1	186	85	s	e	55	46	67	NI	14.129	12
surgery	55	1	174	90	u	e	50	53	68	NI	20.624	18
medical	62	0	152	80	a	n	49	45	58	NI	8.267	9
medical	69	1	173	140	s	e	56	46	65	NI	9.554	9
trauma	20	1	183	78	s	t	50	50	66	NI	12.050	16

Notes:
d_categ
surgery – surgery (general)
neuro –Neurosurgical (non-trauma)
airway: n corresponds to none
Baseline categories: d_categ: medical; sex: 0; awake: a; airway: e; Route: NG

Coefficient		No1		No1 @ 42		No1 @ 85kg		No1 @ 42 yrs and 85kg	
			Estimate		Estimate		Estimate		Estimate
(Intercept)	-22.28	1	-22.28	1	-22.28	1	-22.28	1	-22.28
kg	0.47	75	35.30	75	35.30	85	40.01	85	40.01
age	0.58	19	11.06	42	24.45	19	11.06	42	24.45
NI	-3.56	0	0	0	0	0	0	0	0
neuro	-1.54	0	0	0	0	0	0	0	0
surgery	3.45	0	0	0	0	0	0	0	0
trauma	-4.53	1	-4.53	1	-4.53	1	-4.53	1	-4.53
awake s	6.54	1	6.54	1	6.54	1	6.54	1	6.54
awake u	8.20	0	0	0	0	0	0	0	0
kg:age	-0.01	1425	-11.39	3150	-25.18	1615	-12.91	3570	-28.53
Fitted Value			14.70		14.30		17.88		15.65

With an actual difference of 24, you can see that the estimated difference of 14.7 is quite poor. Thus I would not be confident of the usefulness of the parameter estimates for this model. This can furthermore be seen in the figure below – points on/close to the red line would be correctly predicted.



3 Model excluding weight

Model that excludes weight and surgery type.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	2893.76	1216.635	2.378495	0.036598
sex=1	-13.3128	4.113503	-3.23637	0.007925
age	-5.95539	2.679425	-2.22264	0.048143
NI	139.0378	33.33693	4.170683	0.001561
awake s	1.921729	44.81851	0.042878	0.966567
awake u	204.4956	51.32453	3.984364	0.002143
airway n	-722.457	236.4283	-3.05572	0.010935
airway t	9.342324	3.498009	2.670755	0.021765
cm	-16.7744	6.879493	-2.43832	0.032921
depth_goj	-56.9919	23.90594	-2.38401	0.036243
NI:depth_goj	-2.34662	0.492947	-4.7604	0.00059
age:airway n	11.37585	3.831023	2.969403	0.012759
age:airway t	-0.19243	0.061261	-3.14113	0.009389
awake s:depth_goj	-4.70666	1.486879	-3.16546	0.008991
awake u:depth_goj	-3.232	1.336601	-2.41807	0.034123
cm:depth_goj	0.337312	0.134346	2.510771	0.028947
age:depth_goj	0.080158	0.035597	2.251858	0.045741
age:cm	0.013274	0.006935	1.914061	0.081974
awake s:cm	1.343826	0.576082	2.332698	0.03968
awake u:cm	-0.21198	0.559496	-0.37888	0.711986
NI:cm	-0.1606	0.165516	-0.97027	0.352761

Residual standard error: 2.125 on 11 degrees of freedom
(4 observations deleted due to missingness – no value for depth_b available)
Multiple R-squared: 0.9328, Adjusted R-squared: 0.8107
F-statistic: 7.638 on 20 and 11 DF, p-value: 0.0006731

This R-squared value is brilliant!

The model for someone with sex=1; awake = s; airway = t; route = NG would be:
2893.76-13.3128-5.95539*age+1.921729+9.342324-16.7744*cm-56.9919*depth_goj-0.19243*age-4.70666*depth_goj+0.337312*cm*depth_goj+0.080158*age*depth_goj+0.013274*age*cm+1.343826*cm

This simplifies to:
(2893.76-13.3128+1.921729+9.342324) + age*(-5.95539-0.19243) + cm*(-16.7744+1.343826) + depth_goj*(-56.9919-4.70666) + 0.337312*cm*depth_goj + 0.080158*age*depth_goj +0.013274*age*cm
=2891.711 -6.14782*age -15.43057*cm - 61.69856*depth_goj + 0.337312*cm*depth_goj + 0.080158*age*depth_goj +0.013274*age*cm

A worked example...

		Patient 1		Patient 1 @ 42years		Patient 1 @ 175cm		Patient 1 @ 42 and 175	
	Est.	**Profile**	**Est.**	**Profile**	**Est.**	**Profile**	**Est.**	**Profile**	**Est.**
Intercept	2893.8	1	2893.8	1	2893.8	1	2893.8	1	2893.8
sex1	-13.31	1	-13.31	1	-13.31	1	-13.31	1	-13.31
age	-5.955	19	-113.2	42	-250.1	19	-113.2	42	-250.1
NI	139.0	0	0	0	0	0	0	0	0
awake s	1.92	1	1.92	1	1.92	1	1.92	1	1.92
awake u	204.5	0	0	0	0	0	0	0	0
airway n	-722.5	0	0	0	0	0	0	0	0
airway t	9.342	0	0	0	0	0	0	0	0

cm	-16.78	184	-3086.5	184	-3086.5	175	-2935.5	175	-2935.5
depth_goj	-56.99	52	-2963.6	52	-2963.6	52	-2963.6	52	-2963.6
NI: depth_goj	-2.3466	0	0	0	0	0	0	0	0
age: airway n	11.376	0	0	0	0	0	0	0	0
age: airway t	-0.1924	0	0	0	0	0	0	0	0
awake s: depth_goj	-4.7067	52	-244.75	52	-244.75	52	-244.75	52	-244.75
awake u: depth_goj	-3.232	0	0	0	0	0	0	0	0
cm: depth_goj	0.3373	9568	3227.4	9568	3227.40	9100	3069.53	9100	3069.53
age: depth_goj	0.0802	988	79.20	2184	175.07	988	79.20	2184	175.07
age:cm	0.0133	3496	46.40	7728	102.58	3325	44.13	7350	97.56
awake s: cm	1.3438	184	247.26	184	247.26	175	235.17	175	235.17
awake u: cm	-0.212	0	0	0	0	0	0	0	0
NI:cm	-0.161	0	0	0	0	0	0	0	0
	Fitted Values		74.66		89.73		53.41		65.73

The actual value of depth_b for patient 1 is 76.
The summary of the residuals [Actual Depth – Predicted Depth] of the model

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	St Dev	St Error
-3.263	-0.7323	0.07493	0	0.7287	3.113	1.266033	0.223805

This indicates that the maximum error of the model on this data is 3.263cm.
Clinically, I don't know how "big" an error that is.

But... accounting for surgery type is even better – so it may be worthwhile to include it, as it's not difficult to measure!

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-125.04	23.43871	-5.33476	0.02407
sex = 1	-7.6405	2.389809	-3.19712	0.03535
age	0.222217	0.077659	2.861446	0.00005
NI	179.2562	14.14862	12.66952	0.98452
awake s	-0.09693	4.752216	-0.0204	0.00234
awake u	-44.9451	7.903716	-5.68658	0.63277
airway n	51.9103	102.0961	0.508446	0.01204
airway t	6.893825	1.791932	3.847147	0.03807
cm	0.360687	0.128899	2.798217	0.00004
depth_goj	2.579129	0.189009	13.64554	0.33766
Neurosurgical (non-trauma)	5.058674	4.772528	1.059957	0.13587
surgery (general)	11.61743	6.540816	1.776144	0.26575
trauma	3.860146	3.081719	1.252595	0.00007
NI:depth_goj	-3.59417	0.296035	-12.1411	0.52303
age:airway n	-1.14599	1.669731	-0.68633	0.00183
age:airway t	-0.20102	0.033435	-6.01212	0.06816
age:Neurosurgical (non-trauma)	-0.13056	0.056306	-2.3187	0.02034
age:surgery (general)	-0.31702	0.094644	-3.34961	0.60369
age:trauma	-0.01722	0.031103	-0.55361	0.01906
sex = 1:Neurosurgical (non-trauma)	12.57644	3.688777	3.409379	0.00301
sex = 1:surgery (general)	11.15326	2.076348	5.371576	0.13857
sex = 1:trauma	3.077877	1.747955	1.760845	0.00502
NI:Neurosurgical (non-trauma)	-13.9393	2.923038	-4.76877	0.43035
NI:surgery (general)	-2.5782	3.006725	-0.85748	0.09541
NI:trauma	-6.19344	3.018357	-2.05192	0.08236
age:awake s	-0.17892	0.082531	-2.16792	0.00276
age:awake u	0.781927	0.142717	5.478855	0.02407

Residual standard error: 0.9096 on 5 degrees of freedom
(4 observations deleted due to missingness)
Multiple R-squared: 0.9944, Adjusted R-squared: 0.9653
F-statistic: 34.19 on 26 and 5 DF, p-value: 0.0004691

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	St Dev	St Error
-1.167	-0.0903	0	0	0.06393	0.8628	0.365322	0.064581

With this model, the maximum error of the model on this data is 1.167cm, less than half that of the model without surgery type.

To really assess how reliable the models are, more data would be needed to see how accurate the model predictions are for the new data (data not used to build the model). There isn't a sufficiently large sample size here to withhold data for this model evaluation purpose.