BIOMETRIC AND BIOMECHANIC, A STATISTICAL STUDY OF THE HEIDELBERG SIDE-IMPACT-DATA.

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ABSTRACT

The mechanism of injuries and the capability of the human body to tolerate mechanical loads are of fundamental mean, when a safety equipment of a vehicle is to be examined. At the forensic institute of Heidelberg (Prof. Schmidt) a lot of experiments have been carried out and the collected data-sample previous analysed. Deepen analyses with methods like factor-analysis or discriminatory analysis (i.e. logistic location) reveal that human dimensions and some characteristics of human skeleton bones affect the probability of injuries in a side impact more than mechanical measures like thorax acceleration, -deformation, bending of body parts or things like that. In taking this into account the forecast of injuries in the case of suffering a side collision become more acceptable.

INTRODUCTION

The Heidelberg experiments on side impacts (mobile deformable barrier against passenger car) were sponsored by AIF (Arbeitsgemeinschaft Industrieller Forschungsvereinigungen) and FAT (Forschungsvereinigung Automobiltechnik). It belongs to the field of research called "biomechanic".

To draft a new regulation in the field of passive road safety, often the information of biomechanic research is considered only. But this is just one of todays four most important fields of research in car safety of road accidents:

- analyses of real road accidents,
- crash tests,
- simulation and
- biomechanic.

Meaningful experiments have parameters based on estimations derived from real road accidents. In using anthropotechnical surrogates, not only biomechanical concerns (like capability to endure mechanical load, biofidelity, injury mechanism) are to be considered, but also things like repeatability (in one test house), reproduceability (in several test houses) and consistency (corresponding influence of the real accident scene) are of fundamental importance.

At the beginning the mathematical simulation of accidents was assigned to minimize the number of necessary expensive tests with cars. Today simulations are useful in research of the complicate injury mechanisms as well as in looking for the better design-parameters of the car-body. Progressives belief, that mathematical simulation can be used to extract the registration papers of a new car.

The analyses, reported here, are exclusively belonging to the field of research "biomechanic". Previous analyses have been made at the Heidelberg institut for forensic medicine. Some promising relations between mechanical measures and the probability of appointed degrees of injury severity are reported in /1/. A remark is also found there that in deeper analyses it will be expected to find other character-combinations making any forecast of injuries more reliable.

THE DATA

In the Heidelberg side-impact-tests the impacting vehicle was a moving barrier with a deformable front end (CCMC-MDB). The impacted vehicle was a modified two door OPEL-Kadett-body mounted on a sled. Sled, car-body, seat, post-mortem-test-object (PMTO) and an ajusting mass altogether was as heavy as the impacting vehicle (950 kg).

In each case a sample of 208 measures were collected. But not all sets are complete. Some Characters haven't been given in any case. Other have been kept constant and were meaningless in an analysis. Each character has been signed by an abbreviation (4 digits) and some text to describe the character.

The experiments have been planned by a FAT expert team and were partly determined by available subjects. Some fundamental characters are shown in table 1 in a contingency tabulation:

Table 1 : side impact experiments in Heidelberg (FAT)
some fundamental parameters

Sex	(f female m male)	m	f	m	f	m	f	m	f
Impact velocity	km/h	40		45		50		60	
PMTO	left	4	-	7	3	9	3	4	1
	right	2	3	8	2	12	-	-	-
HSR1-Dummy	left	-	-	-	-	3		-	-
	right	-	-	-	-	2		-	-
HYBRID II-Dummy	left	-	-	-	-	3		-	-
	right	-	-	-	-	1		-	-
APROD-Dummy	left	-	-	-	-	2		-	-
	right	-	-	-	-	3		-	-

Out of the origin acceleration-time-history some additional characters like TTI and VC have been derived by using the author's methods (/3,4/).

It was useful to split the characters in several blocks:

human measures (we like to call it biometric)
- general measures like age, sex, ...
- dimensions like body-weight, -size, ...
- rib-attributes like ultimate load, cross section, ...

mechanical measures
- parameters of experiment like impact velocity, ...
- accelerations, velocities, deformations, ...
- derived characters like TTI, VC, ...

injuries
- individuals like number of rib-fractures, ...
- global information "measured in the AIS-scala"
- other scales (ISS, RIS, ...).

How these blocks are working together is demonstated in fig.1 like a signal diagram commonly practised in control theory.

fig.1 : input, output and parameters to be considered in side impact biomechanical research.

```
                     ******************************
             +-----> *   s i d e   i m p a c t    * >--------+
             |       ******************************          |
             |                    |                          |
             |                    |                          V
    ===============    =========================    =================
       I N P U T          P A R A M E T E R S          O U T P U T
    ===============    =========================    =================

   m e c h a n i c s       b i o m e t r i c          i n j u r i e s

  mechanical measures    human characteristics         injury degrees

     jerk                      age                         AIS
     acceleration              weight                      ISS
     velocity                  height                      RIS
     deformation               circumference          number of fractures
     VTC, ...                   ...                        ...
                 ... TTI ...
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ANALYSIS

methods

About 25 characters in the Heidelberg (FAT) data describe the human body but body-height, arm-length, leg-length and trunk-height are however highly correlated. It wouldn't have made any sense to use all these measures as independent characters in an analysis. In a factor-analysis it is possible, to combine all that correlating characters to only few factors. To avoid problems to interpret these factors, it is useful to take just one original character (for instance the character with the best communality) as representative for the whole factor.

To analyse the relations between measures and injuries a method called "discriminatory-analysis" was used in a particular improved multi-dimensional version of the so called "logistic location" method.

The quality of forecast of the likelihood of certain degrees of injury-severity was to "measure". Some wellknown and some new qualifiers were useful:

LF	the value of the used (logarithm.) likelihood-function.
Pw	the probability (%) of forecast and observation come together. Estimated with likelihood-function.
Vr	the frequency (%) of corresponding forecast and observation. It is less than Pw in which also small amounts of probability are summerized.
Vf	the "frequency (%)" of "wrong forecast" multiplied by "distance of misfired class".
Kk	the contingency-coefficient of the matrix (contingency tabulation) of the observated injury-degrees in the lines and the forecast injury-degrees in columns (Spearman) .

Partly some other qualifiers have been proven without rectification.

To check, wether a character is a good indicator (predictor, responce, criterion) or not, there have been chosen two different bases for comparison. In the first base the biometrical characters have been taken only. In the second base the character VELO (velocity of impacting vehicle) was an additional 'independent' character. Any character then was considered as a good indicator, when the forecast by this character (together with biometric) had better qualifiers than in the bases. This method is (partly) described in /1/ and /2/ also.

injuries

The injuries had been "measured" in the wellknown AIS-scale (abbreviated injury scale) separatly for the different body sections "thorax", "abdomen", "spine", ... Brain injuries have not been analysed, because of the unsolved problem on how to measure at a PMTO.

In the AIS-scale there is no difference between cases with more than one injury and cases with just one injury. In the ISS (injury severity score the three most severe (AIS-scaled) injuries are squared and added. It was found that forecast of ISS (in a special classification) has a higher quality than AIS. Some countable measures like "number of broken ribs" and "number of rib-fractures" have also been analysed.

RESULTS

It was impossible to analyse all information contained in the Heidelberg side impact data in the meantime. A first rough estimation gave the following survey.

age and biometrics

Similar investigations /1,3/ showed a predominant role of human age in biomechanical relations, above all when fractures of skeleton bones had to be predicted. This is unsatisfactory, because of a causation between age and injury risk must be rejected. It is wellknown that the bone-stucture changes during human life. In terms of statistics one speaks in those cases about "hidden parameters".

Deepen analyses showed indeed that the biometrical characters derived here predict skeleton injury risk much better than "age". Abdominal injuries are not at all related to "age" but well to biometric. There are obvious extremely different mechanism when abdominal injuries or rib fractures occur. That kind of injury should not be mixed in an efficient analysis.

mechanical measures

The total amount of mechanical measures have been analysed step by step together with the biometrical characters. According to this it was found and in the enclosed figures demonstrated that the original measures like jerk, acceleration, velocity, ..., connected with biometrics are much better qualified to predetermine certain degrees of injuries than others like TTI, with age, and VTC, without any biometrical information.

human measures

The biometrical characters were split into 3 groups:

- general measures like age, sex and weight.
  impact side is to be considered as a biometrical measure, because of the unsymmetrical human body, above all in inner organs.
- body dimensions
  height, length, circumference, ...
- rib attributes (measured in a special procedure)
  ultimate load, ultimate deformation, cross section ...

First of all the separate groups and then the representatives of all groups together has been analysed. Correlation-coefficients of the general measures are shown in table 2.

Table 2 : Correlation of the general human measures (Bravais-Paerson/Spaerman)

Character	SEX	ALT	GEW	GELE
SEX : sex	-----	-0.12	-0.42	-0.01
ALT : age	-0.12	-----	0.14	0.05
GEW : body-weight	-0.42	0.14	-----	0.23
GELE : liver weight	-0.01	0.05	0.23	-----

These characters are not enough correlated to do a helpful factor-analysis.

The human dimensions have such correlations (table 3). The 14 characters are represented by 3 factors (fig.2,3). In these factors the information remains to 71.6 %. The first factor (40.9 % of information) can be interpreted as "human dimension". Although the body height isn't dominant it can with success be used as the representative. It is easy to know, easy to understand and less correlated to the representatives of the other factors (< .14). The second factor (21.5 %) can be interpreted as quotient of vertical heights and horizontal circumferences. We called it "slenderness". Its representative is SIHO / AUMF. The third factor with less then 10 % of communality represents the head dimensions in relation to that of the trunk and its representative is HUT / BEKO. In this way human body dimensions are represented by the 3 characters

GROS : body height
SLEN : body slenderness
VKOR : head-trunk relation

fig.2 : representatives of human dimensions
factor 1 and factor 2

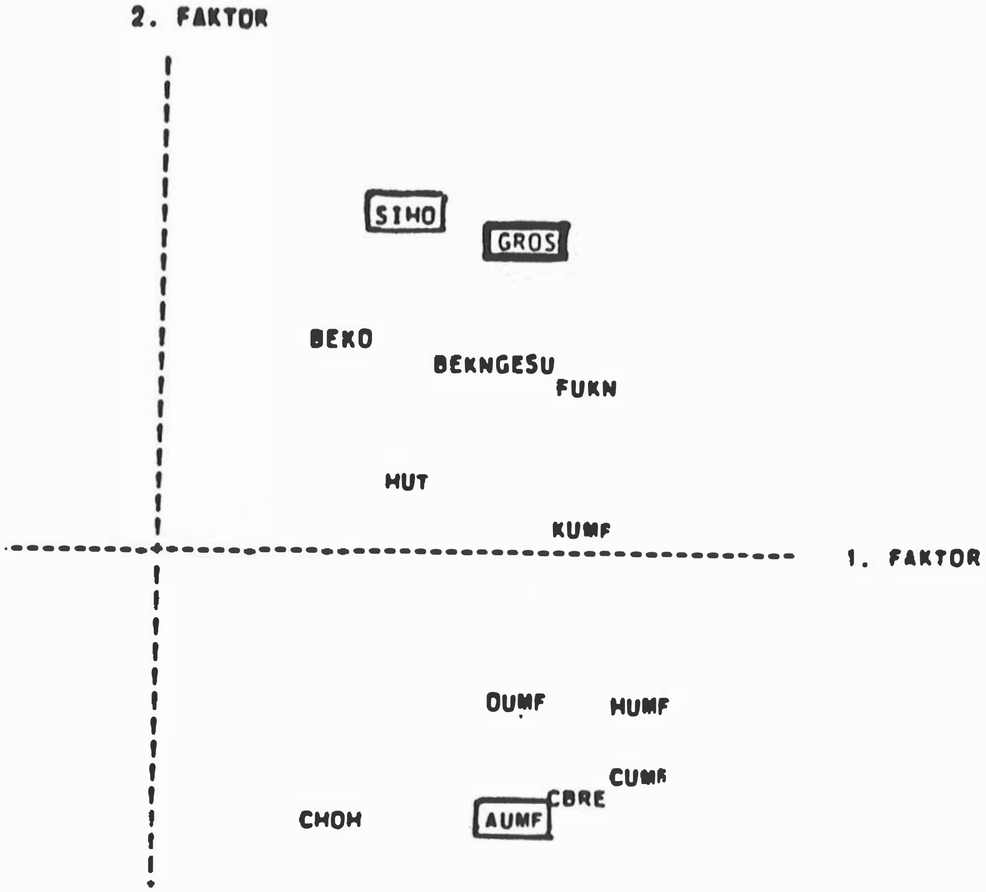

fig.3 : representatives of human dimensions
factor 3

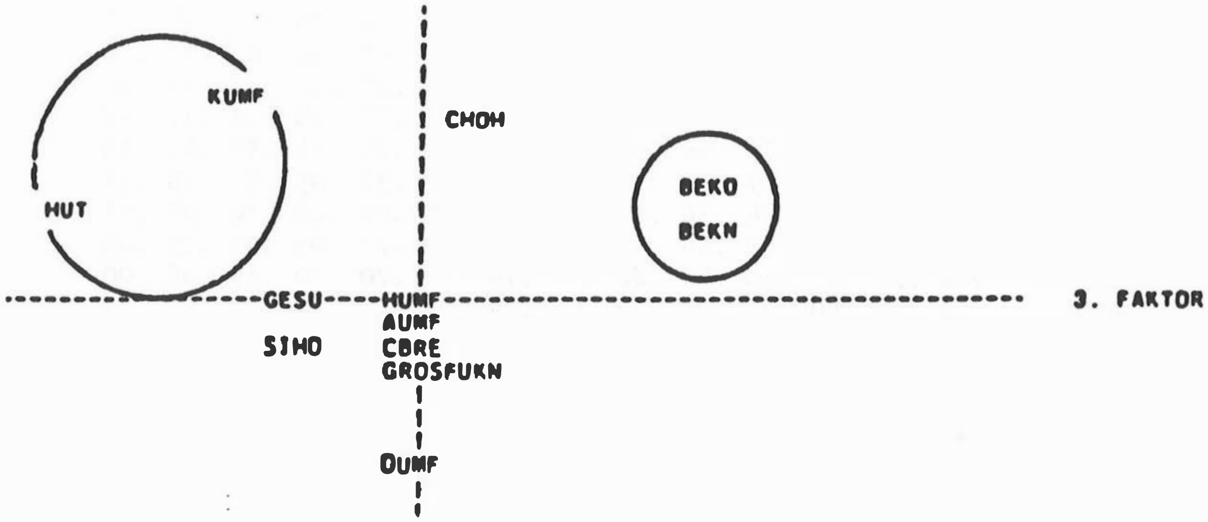

Table 3 : Correlation of PMTO dimensions

(Bravais-Paerson/Spaerman)

Character

GROS : body-height
HUT : hat size
KUMF : head circumference
HUMF : neck circumference
OUMF : arm circumference
CUMF : chest circumference
CHOH : thorax X-X

Character

CBRE : thorax Y-Y
AUMF : abdomen circumference
GESU : shoulder height
SIHO : torso height
BEKN : pelvis-knee distance
FUKN : calcaneus-knee distance
BEKO : pelvis-head distance

Character	GROS	HUT	KUMF	HUMF	OUMF	CUMF	CHOH	CBRE	AUMF	GESU	SIHO	BEKN	FUKN	BEKO
GROS	---	.33	.38	.31	.28	.17	-.15	.14	.04	.60	.75	.58	.79	.49
HUT	.33	---	.54	.27	.22	.29	-.01	.22	.28	.44	.36	.03	.29	.10
KUMF	.38	.54	---	.62	.34	.47	.24	.34	.42	.50	.32	.37	.47	.21
HUMF	.31	.27	.62	---	.71	.77	.44	.70	.65	.33	.19	.32	.47	.18
OUMF	.28	.22	.34	.71	---	.67	.30	.56	.60	.25	.14	.19	.40	.15
CUMF	.17	.29	.47	.77	.67	---	.51	.83	.88	.32	.05	.31	.46	.11
CHOH	-.15	-.01	.24	.44	.30	.51	---	.49	.48	-.02	-.02	.10	.02	-.02
CBRE	.14	.22	.34	.70	.56	.83	.49	---	.79	.29	-.04	.24	.39	.05
AUMF	.04	.28	.42	.65	.60	.88	.48	.79	---	.20	-.10	.15	.36	.00
GESU	.60	.44	.50	.33	.25	.32	-.02	.29	.20	---	.67	.42	.52	.23
SIHO	.75	.36	.32	.19	.14	.05	-.02	-.04	-.10	.67	---	.43	.52	.29
BEKN	.58	.03	.37	.32	.19	.31	.10	.24	.15	.42	.43	---	.61	.58
FUKN	.79	.29	.47	.47	.40	.46	.02	.39	.36	.52	.52	.61	---	.48
BEKO	.49	.10	.21	.18	.15	.11	-.02	.05	.00	.23	.29	.58	.48	---

rib attributes

Ultimate load, cross section and breaking deformation had been measured at the 6th. and 7th. rib. The concentration of these 6 characters led to 2 factors with more than 80 % cummunality but difficult to interpret results. It was more succesful to derive first some additional but easy to understand characters and then to pick out two of it, signed with an asterix in table 4.

Table 4 : additional rib attributes

BSP6 : breaking stress 6. rib (load / deformation)
BSP7 : breaking stress 7. rib (load / deformation)
BEN6 : spec. breaking stress 6. rib (stress / cross section)
BEN7 : spec. breaking stress 7. rib (stress / cross section)
ENC6 : energy capacity 6. rib (load * deformation)
ENC7 : energy capacity 7. rib (load * deformation)
* BENE : energy capacity of ribs .5 * (ENC6 + ENC7)
EMO6 : elasticity modulus 6. rib (stress / deformation)
EMO7 : elasticity modulus 7. rib (stress / deformation)
* EMOD : elasticity modulus of ribs (stress / deformation)

The selected characters are independent to the "human dimensions" and very succesful in statistical analyses.

mechanical measures

On several parts of the human body accelerations were measured. Surprisingly the time of maximum accelerations and the acceleration itselves were found diametrically opposed in a factor plan. The idea to take the jerk (differentiation of accelerations) as additional information was therefore not to far. Via integrations of acceleration we get velocity and deformation. At least we have the five different qualities of mechanical measures :

- o jerk
- o acceleration
- o velocity
- o deformation
- o SI, HIC (severity index)

Thorax-deformations didn't help to a good forecast of any degree of thoracic injuries; for abdominal injuries however the prediction quality was acceptable.

Surprisingly the measures in X-X-direction at sternum and spine in thoracic region improve the quality of forecast of thoracic injuries. This is explainable by interpretation the thorax as a ring structure.

LITERATURE

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Phase II: Ansätze für Verletzungsprädiktionen

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/3/ Eppinger, R. H. et al : Development of Dummy and Injury Index for NHTSA's Thoracic Side Impact Protection Research program.
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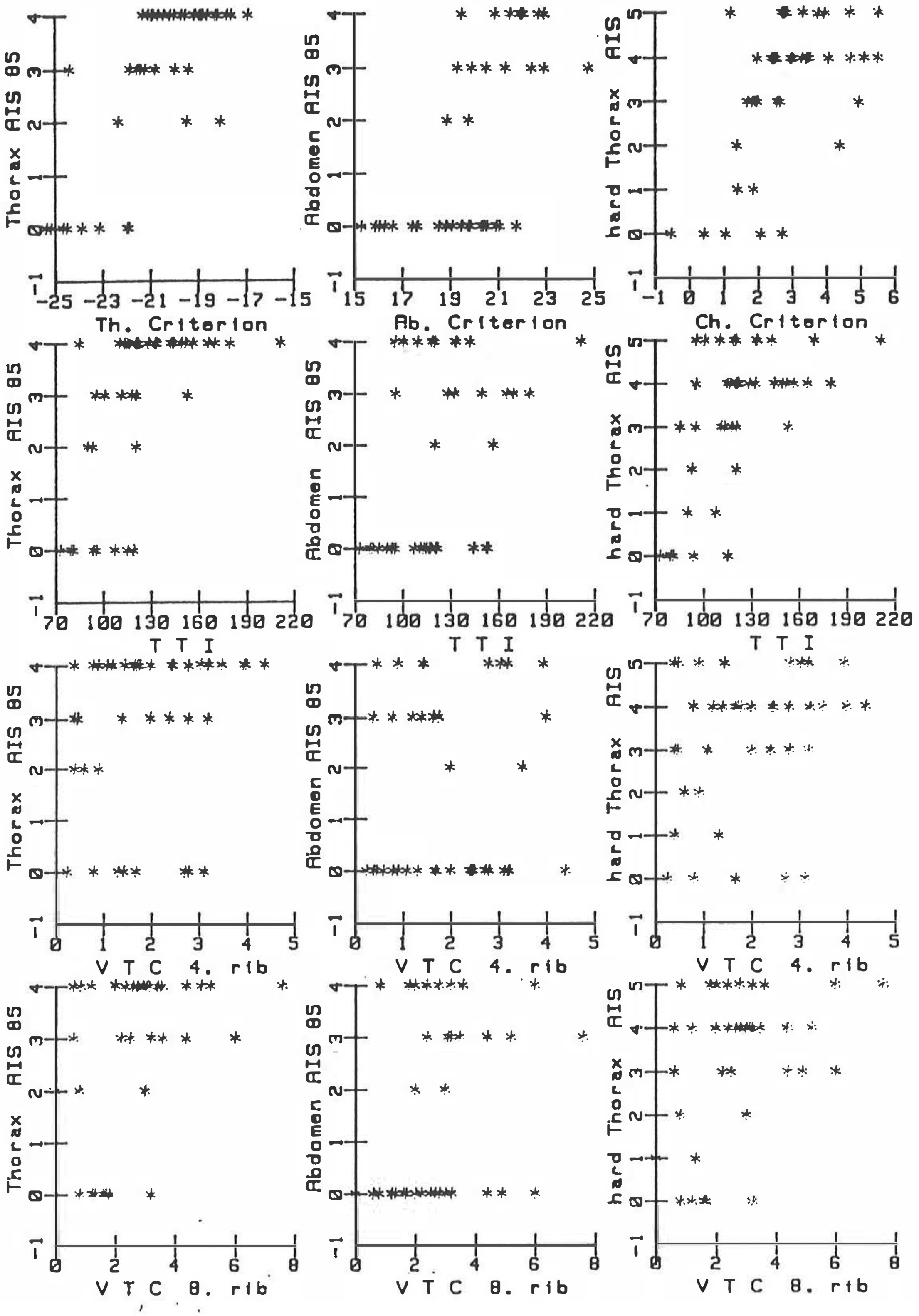

Heidelberg side impact data
Thorax / Abdomen / h. Thorax
biometrics / TTI / VTC

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