# Investigations into the rib strain measurements as a basis for injury criteria on the THOR-NT dummy

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## ABSTRACT

*This paper presents the results from a study performed in the framework of the European project THORAX. The objective of the study is to develop a new thoracic injury criterion based on the THOR-NT dummy rib deformations.*

*Rib fractures were found to be strongly related to rib strains on PMHS in hub and airbag loading tests (Trosseille et al., 2008). The strain measurements on the ribs of the THOR dummy could then be a good basis for a thoracic injury criterion.*

*In order to confirm this hypothesis, the field of PMHS testing was enlarged by including belt and harness loading tests. Then, hub, airbag, belt and harness PMHS tests were duplicated on a THOR-NT equipped with 140 strain gages on the ribs. Finally, the PMHS strain patterns were compared to the THOR-NT strain patterns to evaluate if this instrumentation could be used for the development of an injury criterion.*

*This paper presents the first observations made from the comparison of the rib strain patterns of the PMHS tests with those found in the paired THOR-NT tests and gives some perspectives about the use of this instrumentation in the development of a thoracic injury criterion.*

## INTRODUCTION

This paper presents the results from a study performed in the framework of the European project THORAX. The objective of this project is the development of an improved thorax for the THOR dummy, with capabilities to predict the risk whatever the restraining system. It is to say that the risk should be evaluated properly for a belt only system, an airbag or a combined restraining system. However, instead of developing a completely new thorax, it was decided to investigate the possibility to achieve this goal with an improved instrumentation and to see if a criterion could be developed on the existing dummy, with minor

modifications. The objective of the study is to develop a new thoracic injury criterion based on the THOR-NT dummy rib deformations.

Rib fractures were found to be strongly related to rib strains on PMHS in hub and airbag loading tests as shown in Figure 1 (Trosseille et al., 2008). The strain measurements on the ribs of the THOR dummy could then be a good basis for a thoracic injury criterion.
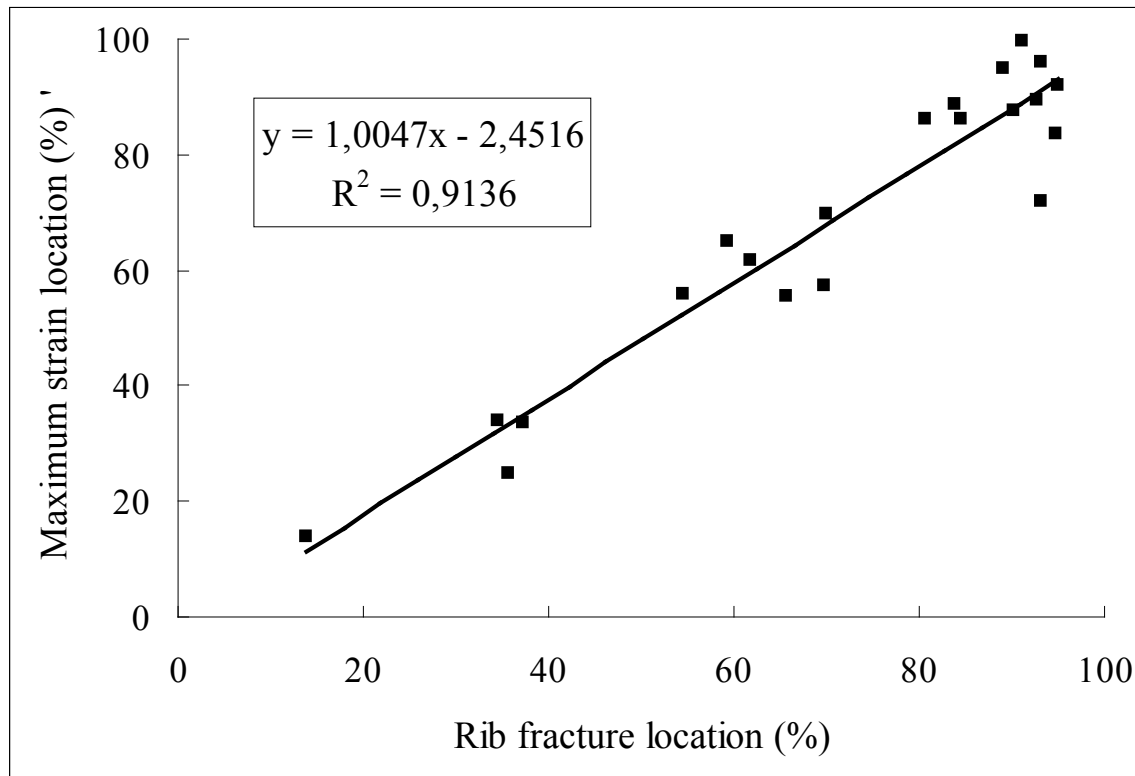


The plotted equation reads:

$$y = 1{,}0047x - 2{,}4516$$
$$R^2 = 0{,}9136$$

**Figure 1. Maximum strain location as a function of actual rib fracture location (from Trosseille et al., 2008)**

It was shown that the rib strain profiles were useful to discriminate between different loading configurations. Figure 2 shows a comparison between airbag and impactor tests in terms of normalized strain as a function of the curvilinear abscissa. We can see a significantly different shape of profile. For the airbag, almost all the strains are in tension, whereas they fall in compression at a higher abscissa for the impactor.
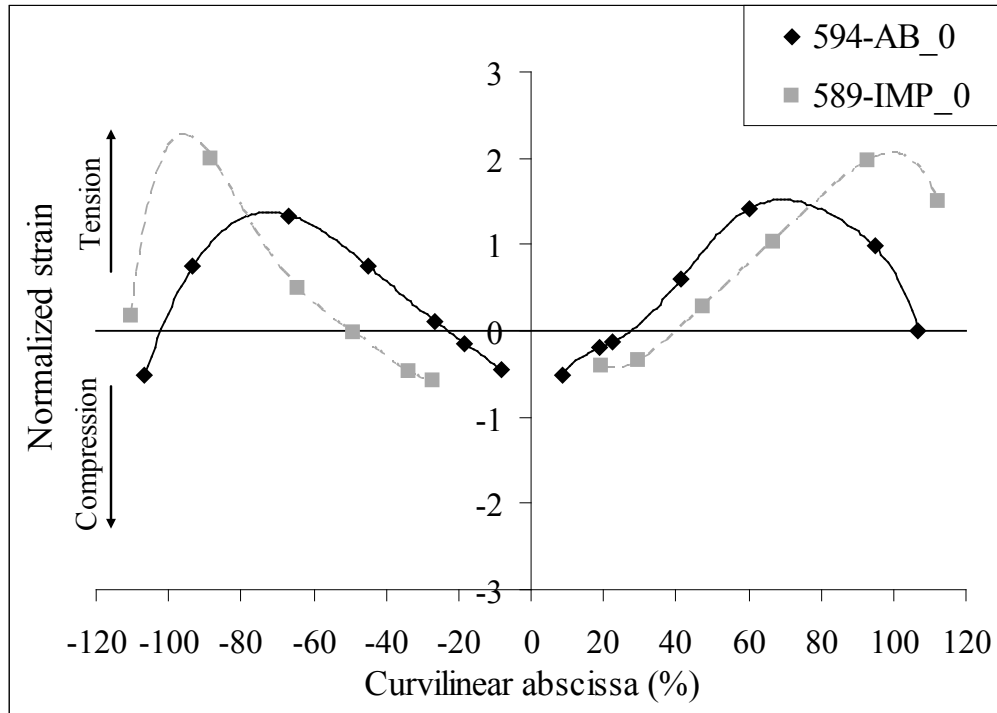
**Figure 2. Normalized strain as a function of the curvilinear abscissa**

As an illustration, Figure 3 shows a representation of the 5th costal ring loaded by an airbag. As the thorax is compressed, the external part of the rib is in tension. A compression strain means that the costal rib is extended.
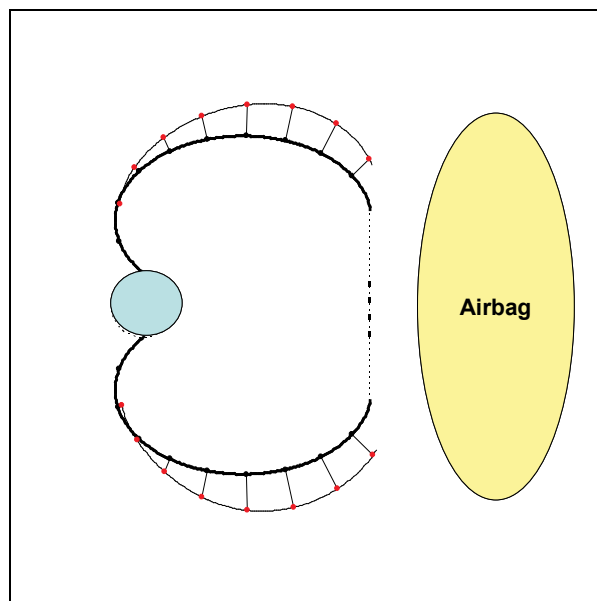


**Figure 3. 5th rib normalized strain profiles drawn along a schematic costal ring (The compression is inside the chest cavity. The tension is outside the chest cavity).**

Moreover, the comparison of the different levels of ribs allow to better understand the behaviour of the rib cage. Figure 4 presents the normalized strain profiles for an airbag loading. We can see that the lower ribs are mainly in compression while the upper ribs are in tension. It is as if the lower costal rings were extended. However, this was done only for airbag and impactor tests in 2008.
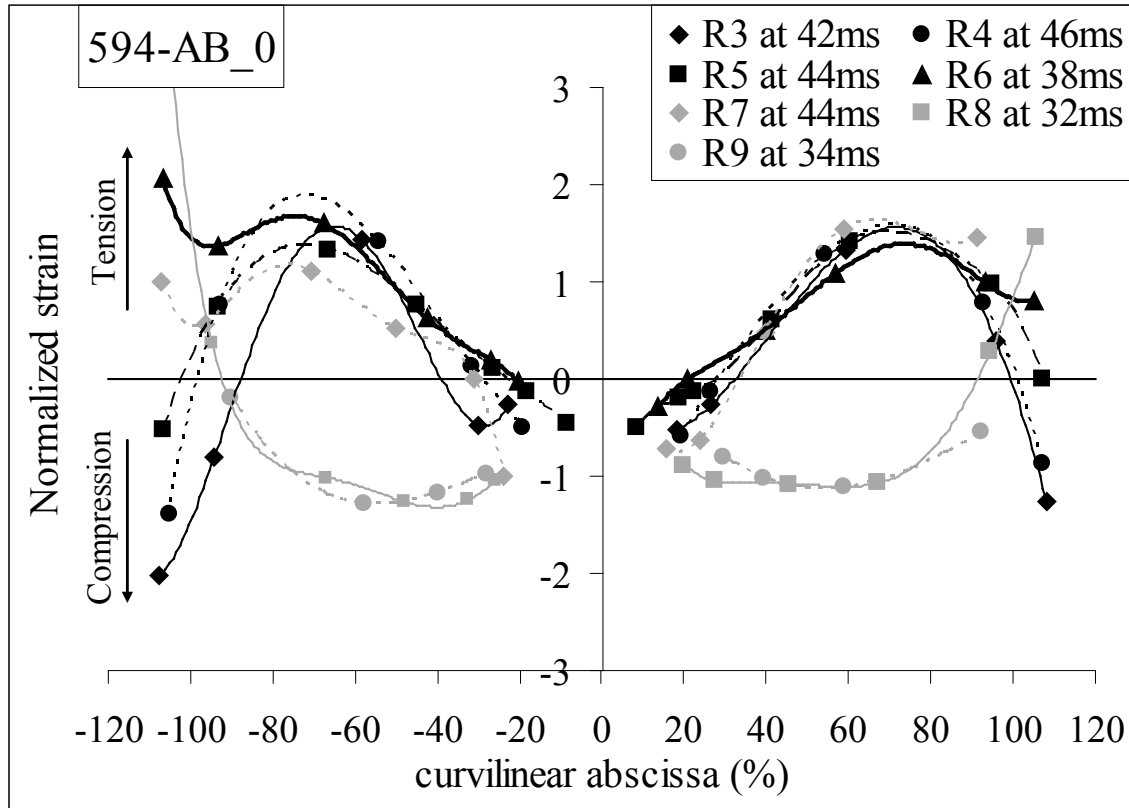


**Figure 4. Normalized strain as a function of the curvilinear abscissa**

The field of PMHS testing was enlarged by including belt and harness loading tests. Then, hub, airbag, belt and harness PMHS tests were duplicated on a THOR-NT equipped with 140 strain gages on the ribs. Finally, the PMHS strain patterns were compared to the THOR-NT strain patterns to evaluate if this instrumentation could be used for the development of an injury criterion. This paper presents the first observations made from the comparison of the rib strain patterns of the PMHS tests with those found in the paired THOR-NT tests and gives some perspectives about the use of this instrumentation in the development of a thoracic injury criterion. However, only the hub, airbag and belt tests analysis are presented.

## METHODS

The PMHS tests duplicated with THOR-NT dummy are presented in Figure 5. It consist on airbag, impactor, belt and harness dynamic loading. The PMHS were equiped with strain gauges on the ribs so that strain profiles can be drawn.
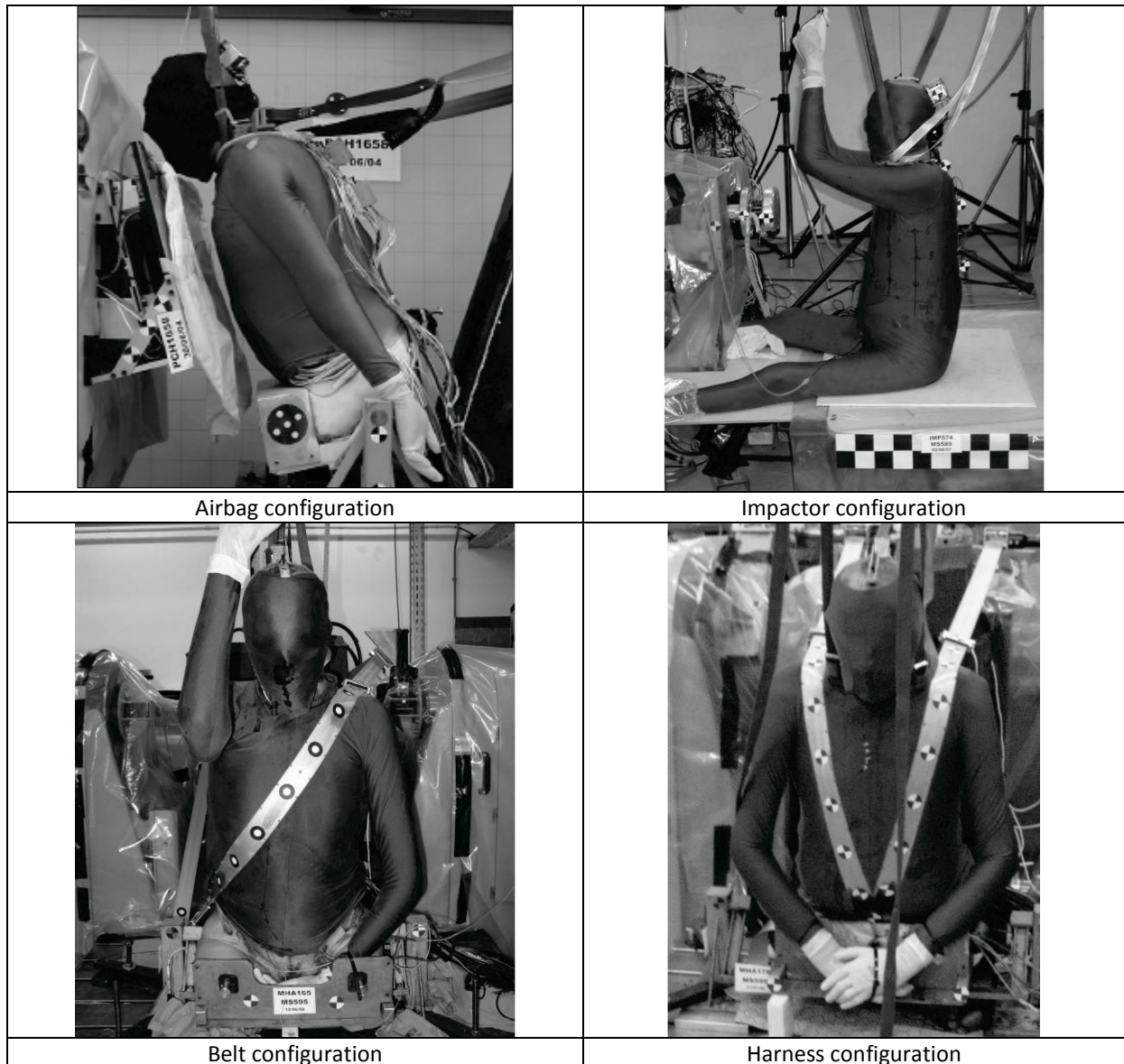
| | |
|---|---|
| Airbag configuration | Impactor configuration |
| Belt configuration | Harness configuration |

**Figure 5. PMHS test configurations**

## Strain analysis

Local responses are based on the strain gauges analysis presented in Trosseille et al., 2008. Strain analysis involved two aspects :
- spatial strain profile
- temporal strain magnitude

The strain profile (strain as a function of the curvilinear abscissa) can be drawn, as illustrated in Figure 6 for each costal ring.
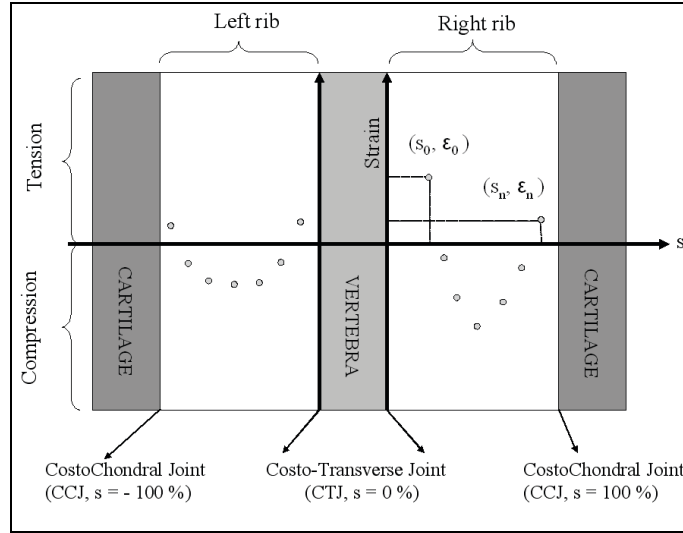
**Figure 6. Strain profile**

In order to allow for the comparison of different tests or ribs, the strains were normalized. For that purpose, an effective strain, $\varepsilon_{RMS}$ (Root Mean Square) was calculated for each costal rib. Then, each strain of the costal ring was divided by the effective strain to obtain a normalized strain $\varepsilon_N(s, t)$.

$$\varepsilon_{RMS}(t) = \sqrt{\frac{1}{\left((s1-sn)_{left} + (sn-s1)_{right}\right)}\left(\left(\int_{sn}^{s1}(\varepsilon(s,t))^2\,ds\right)_{left} + \left(\int_{sn}^{s1}(\varepsilon(s,t))^2\,ds\right)_{right}\right)}$$

where $\varepsilon(s, t)$ is the strain measured at the curvilinear abscissa s as a function of time, s1 the curvilinear abscissa of the first gauge and sn is the curvilinear abscissa of the $n^{th}$ gauge

$$\varepsilon_N(s,t) = \frac{\varepsilon(s,t)}{\varepsilon_{RMS}(t)}$$

## THOR/PMHS rib association

PMHS have 12 ribs and THOR have 7 ribs. PMHS Floating ribs were excluded. Each PMHS rib was associated to the THOR rib which is the closest to its costo-condral joint. Then, as shown in Figure 7, the 1st THOR rib is associated to the 1st and 2nd PMHS ribs, the 3rd THOR rib is associated to the 4th and 5th PMHS ribs and the 7th THOR rib to the 9th and 10th PMHS ribs.
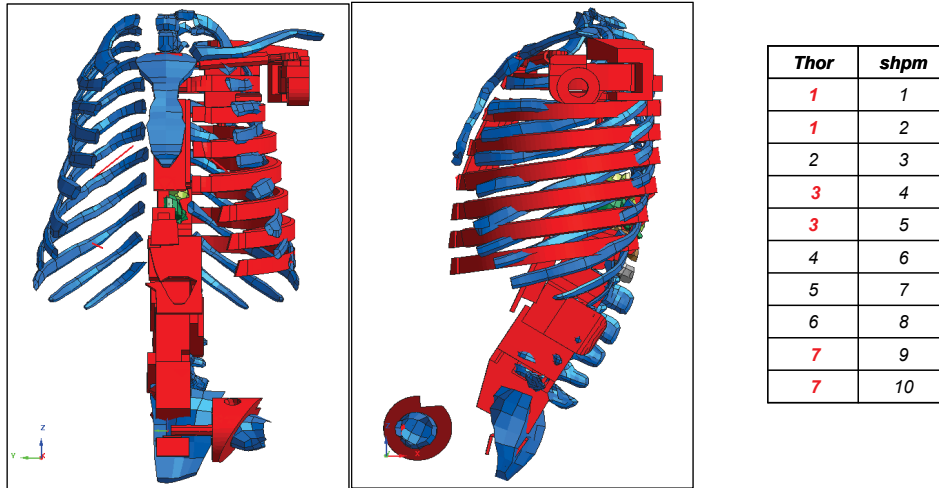
| Thor | shpm |
|------|------|
| *1* | 1 |
| *1* | 2 |
| 2 | 3 |
| *3* | 4 |
| *3* | 5 |
| 4 | 6 |
| 5 | 7 |
| 6 | 8 |
| *7* | 9 |
| *7* | 10 |

**Figure 7. THOR/PMHS rib association**

## RESULTS

The results are presented in Figure 8 to Figure 16 in terms of normalized and RMS strains and in Figure 17 and Figure 18 in terms of actual strains.

The normalized strain profiles and RMS for a PMHS airbag test are presented in Figure 8. We can see here that the upper ribs are mainly in tension (positive normalized strains) and the lower ribs in compression (negative normalized strains). However, the magnitude of the signal (expressed by the RMS strain), as shown in the lower graph, are lower for the lower ribs.
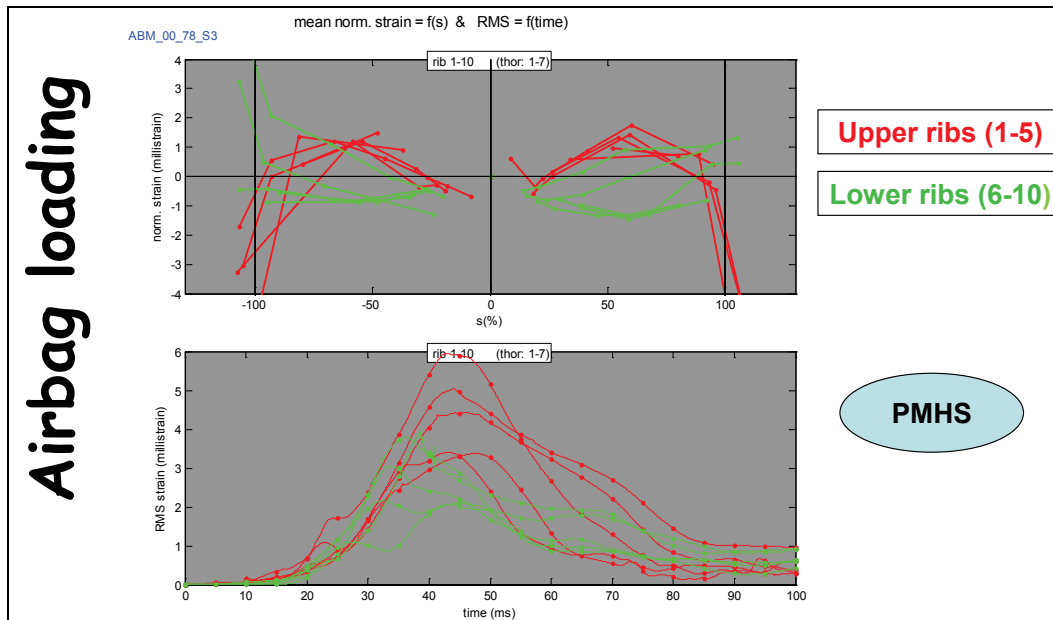


**Figure 8. Normalized strain profiles and RMS for a PMHS airbag test.**

For the PMHS impactor tests (Figure 9), the upper ribs are, as for airbag, mainly in compression, but the deformation is concentrated close to the sternum. As for the airbag, the lower ribs are in tension. Its like if something pushed the ribs from inside. When the upper chest is compressed, the abdomen tends to inflate. However, this phenomenon is of a smaller magnitude than the compression.
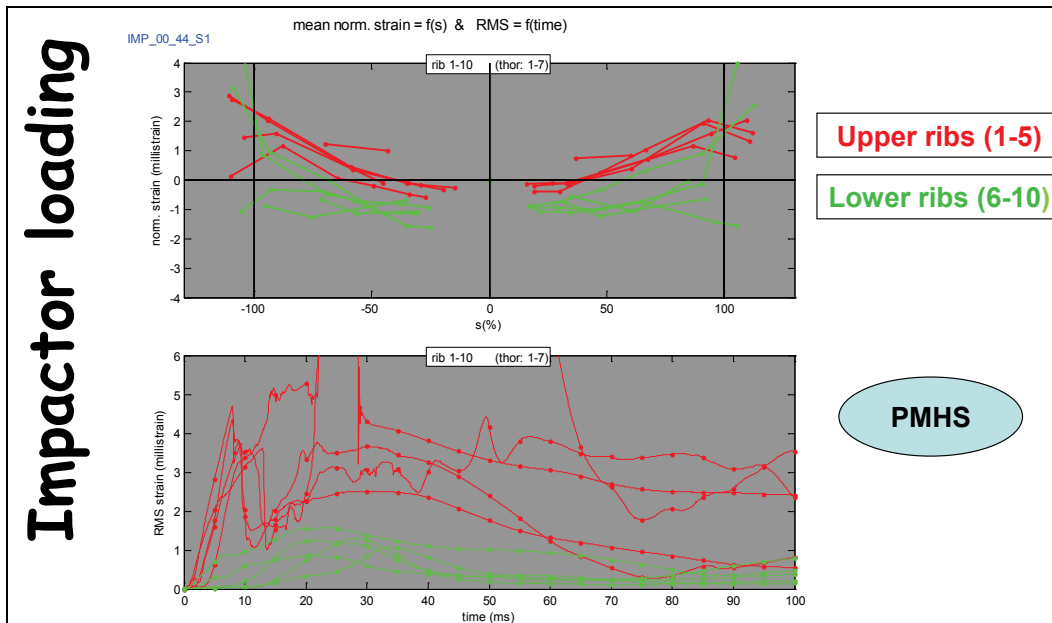
**Figure 9. Normalized strain profiles and RMS for a PMHS impactor test.**

The normalized strain profiles and RMS for a PMHS belt test are presented in Figure 10. On the right part, all the ribs are almost in tension. For the lower ribs, it corresponds to the loading of the belt. On the left part, the shape ressembles more to an airbag or an impactor loading, with the upper part in tension and the lower part in compression. For the lower ribs, it corresponds to the part which is not loaded. Then the inside organs push the ribs outside.
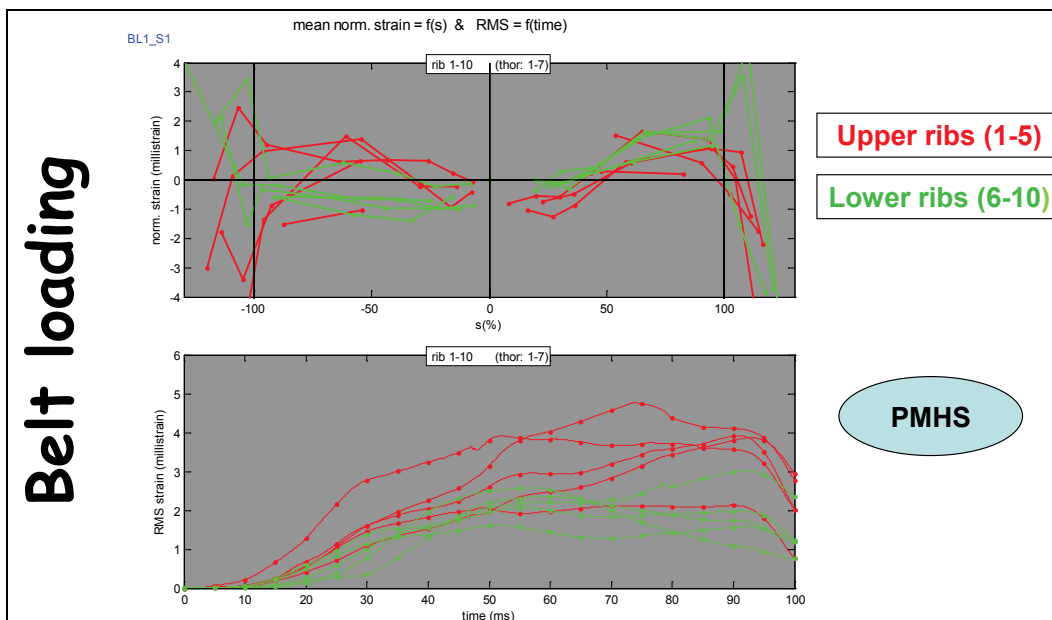


**Figure 10. Normalized strain profiles and RMS for a PMHS belt test.**

The normalized strain profiles and RMS for the THOR airbag test are presented in Figure 11. The upper ribs are in tension like for PMHS. On the contrary, the lower ribs are also in tension. As for the PMHS, the magnitude of the signal is lower for lower ribs.
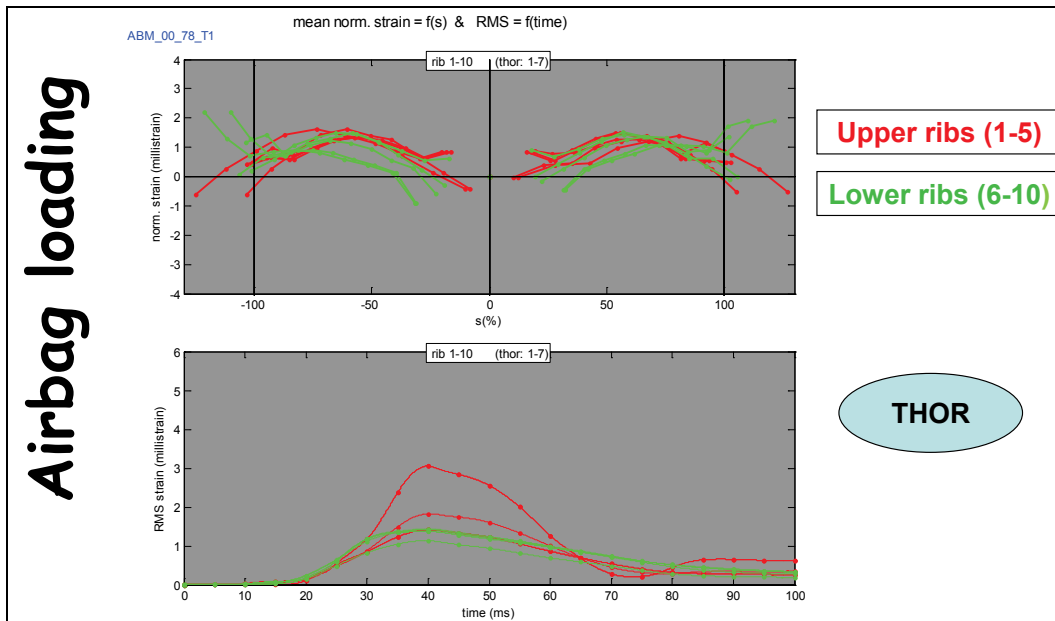


**Figure 11. Normalized strain profiles and RMS for a THOR airbag test.**

For comparison purposes, the PMHS and THOR profiles are presented together in Figure 12. The difference is obvious, due to the fact that nothing from inside the dummy can push the ribs outside.
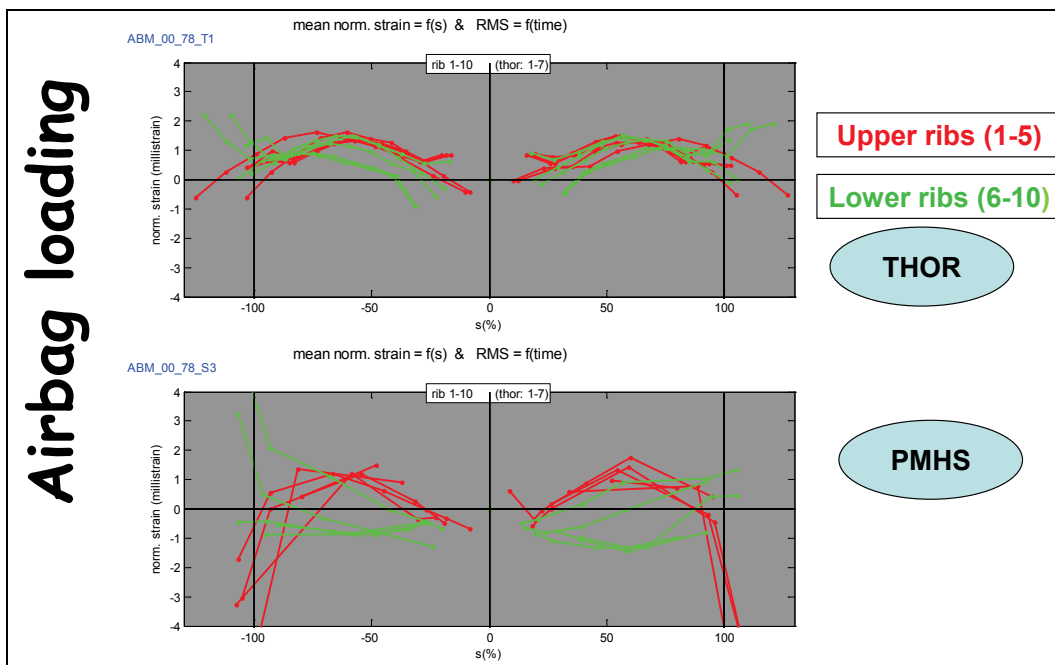


**Figure 12. Comparison of the THOR and PMHS normalized strain profiles in case of airbag loading.**

The THOR impactor tests (Figure 13) demonstrate almost the same situation than the airbag tests, but with very low strains for the lower ribs.
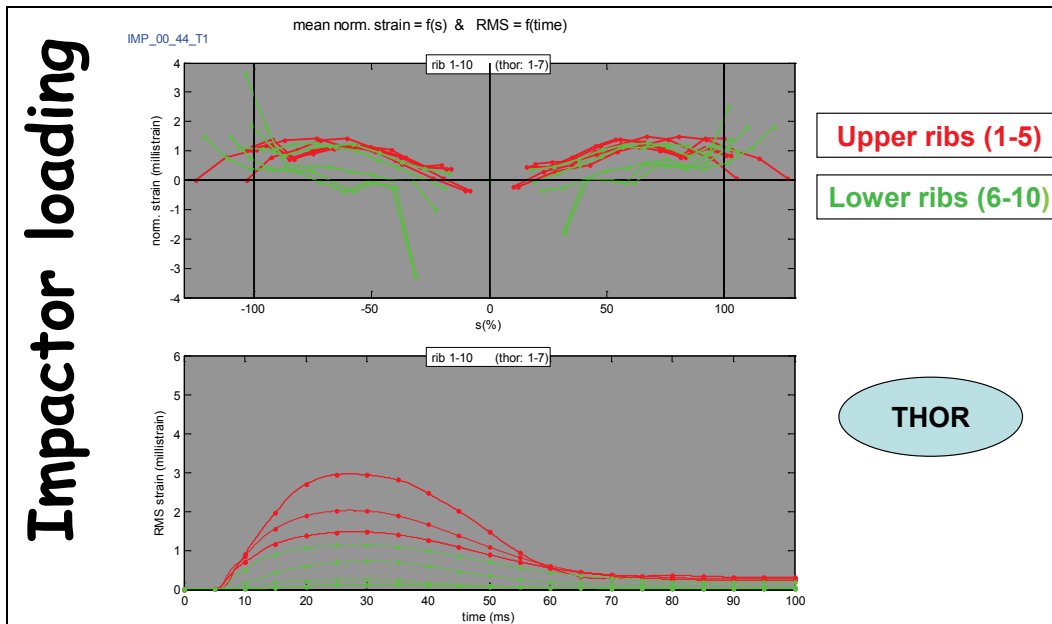


**Figure 13. Normalized strain profiles and RMS for a THOR impactor tests.**

Moreover, the profiles of the upper ribs don't have the same shape than for PMHS (Figure 14). They are very similar to the one observed for airbag loading.
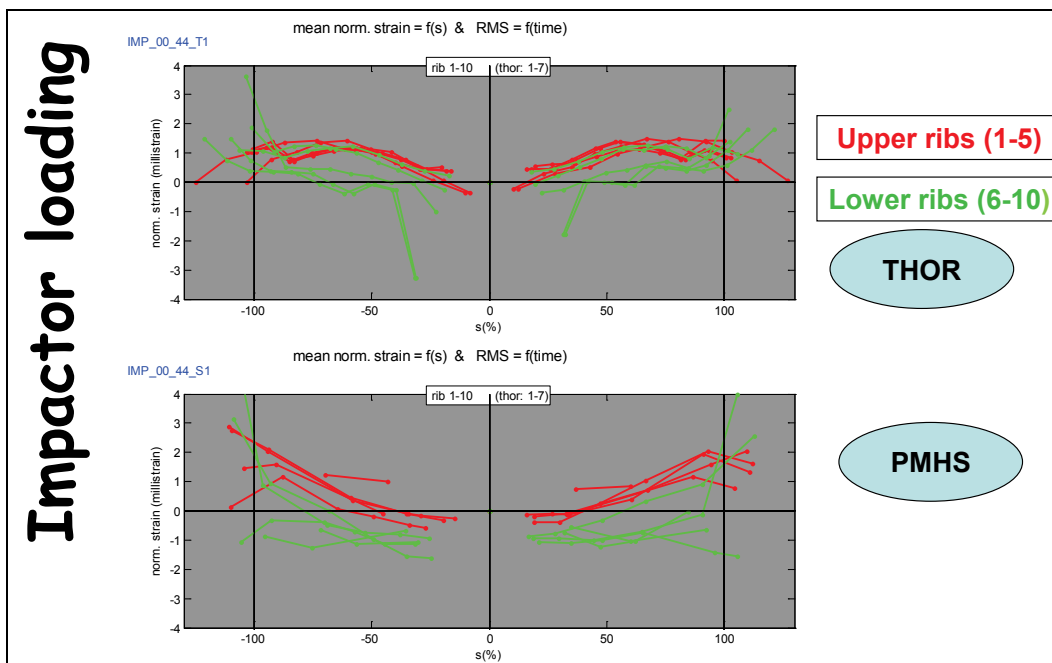


**Figure 14. Comparison of the THOR and PMHS normalized strain profiles in case of impactor loading.**

Finally, Figure 15 shows the normalized strain profiles and RMS for the THOR belt tests. We can see that the right ribs are in tension, while only the ribs 1 and 2 are in tension on the left. The others are almost not loaded.
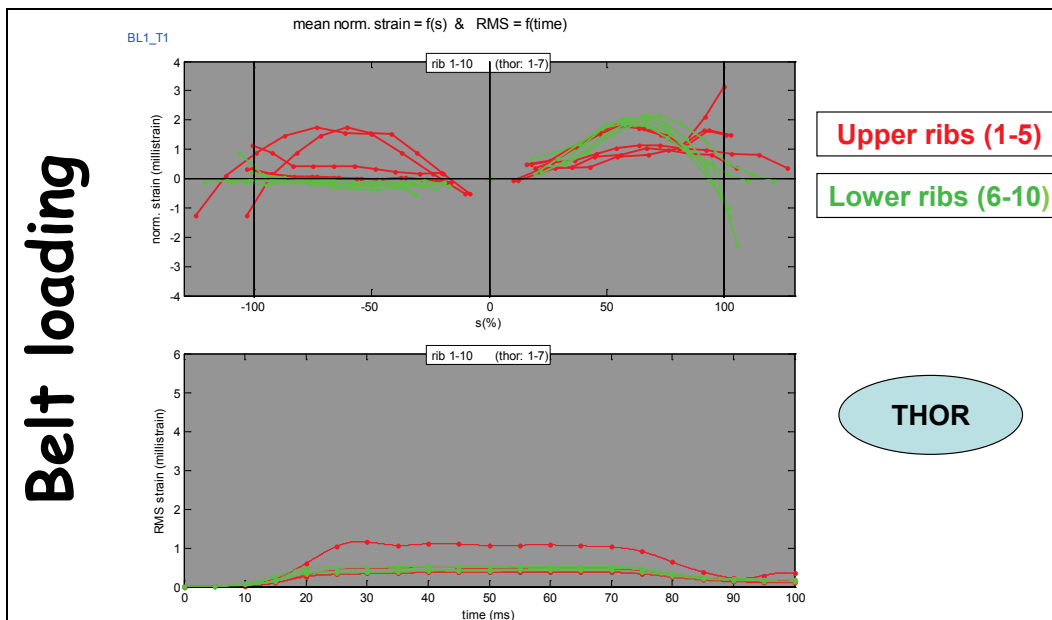


**Figure 15. Normalized strain profiles and RMS for a THOR belt tests.**

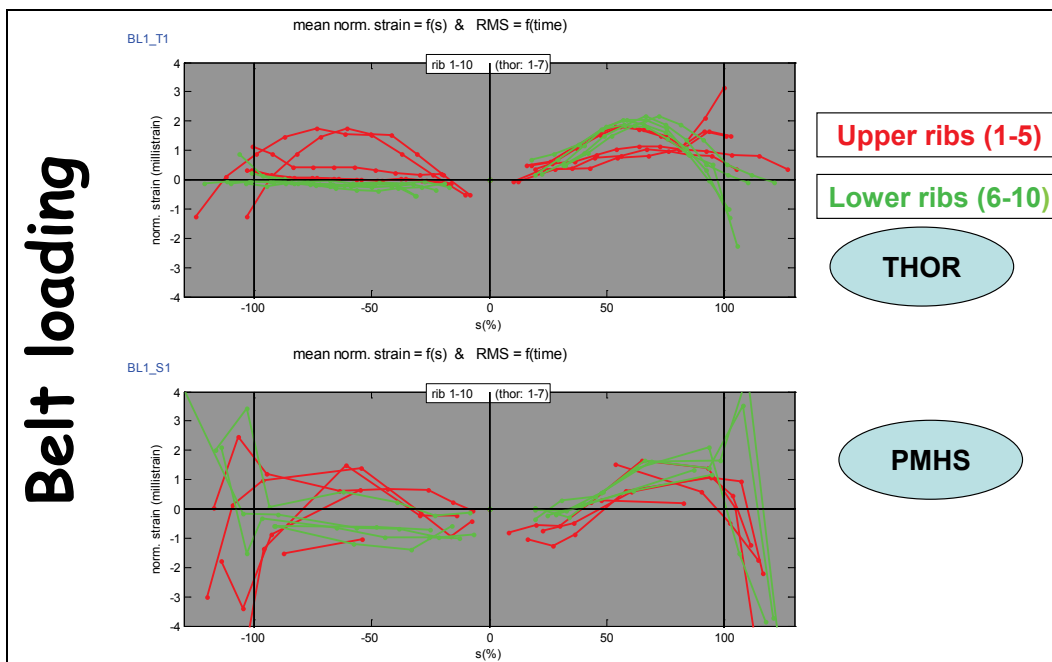If we compare the THOR to the PMHS rib profiles (Figure 16), we see a clear difference on the left part.



**Figure 16. Comparison of the THOR and PMHS normalized strain profiles in case of belt loading.**

Normalized profiles give usefull information on the loading modes for each of the configurations. However looking at the raw profiles allows to see if the different loadings are taken into account properly in terms of magnitude. For instance if the modes are correctly reproduced but not the relative magnitudes between for instance a belt and an airbag, then the strain measurement cannot assess properly the relative risks.

Figure 17 for the upper ribs and Figure 18 for the lower ribs show an exemple of such an anlysis. It must be noted that the strains of the ribs 3 to 7 were scaled because they were very low compared to the PMHS strains. However, the scaling factors were the same for all the configurations. This is necessary because the sections of the THOR ribs do not account for human variations. This could be corrected on a modified dummy, but a scaling method could also be a solution.

For the 4th rib, we can see that the airbag and impactor tests are quite well repoduced compared to 2 PMHS. However, the left part of the belt loading profile is not good. For the 5th rib, we see that the shape has changed for the PMHS impactor tests, but not for the THOR.

We see on the 7th rib that the strains are almost at zero for the left part of the belt strain profile. The other profiles are not so bad. On the 9th rib, almost all the strains are in compression for the PMHS while they are slightly positive or null for the THOR. This cannot be corrected by scaling.
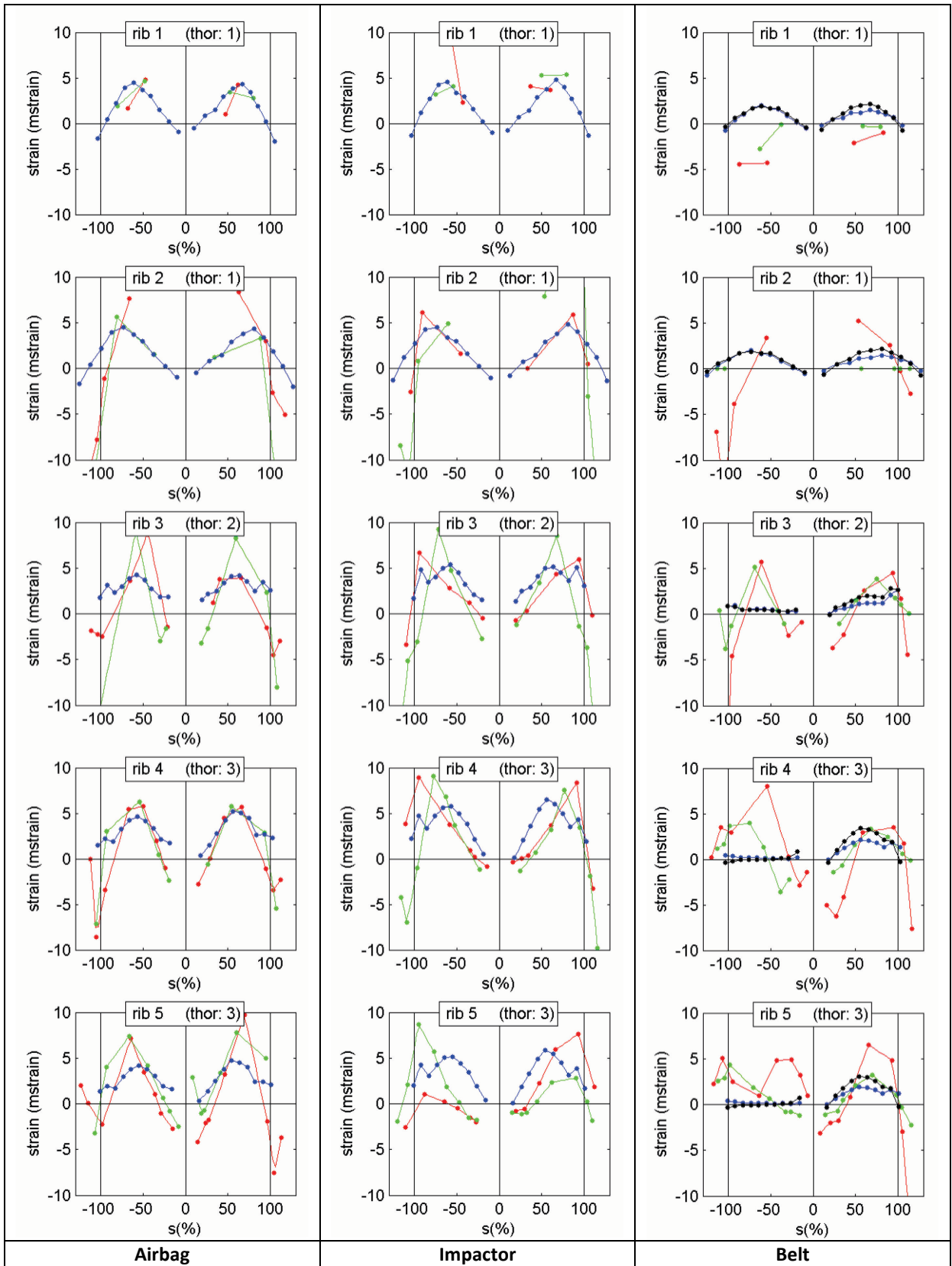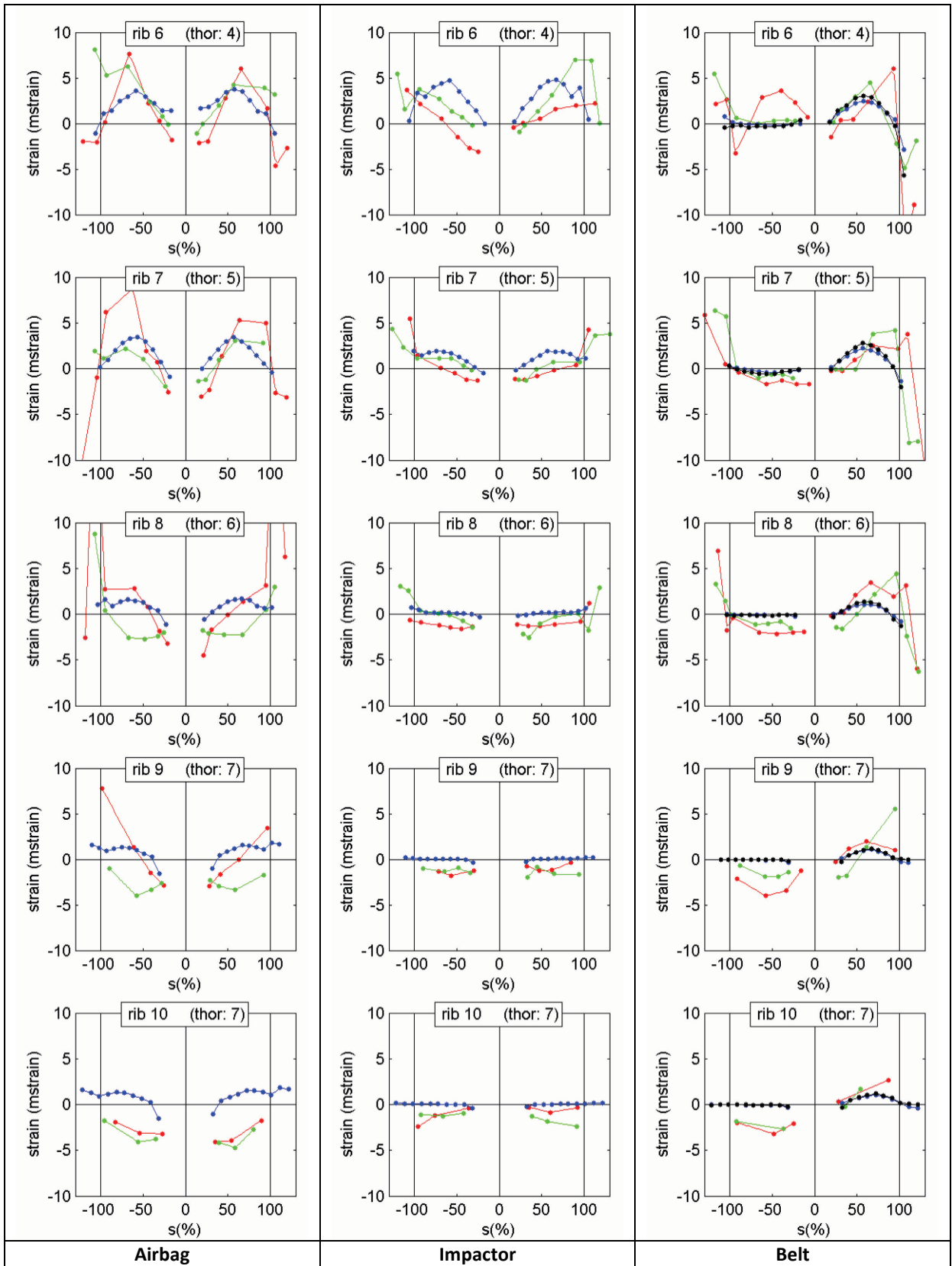
**Figure 17. Upper rib strain profiles**

**Figure 18. Lower rib strain profiles**

# CONCLUSIONS

Hub, airbag and belt PMHS tests were duplicated on a THOR-NT equipped with 140 strain gages on the ribs. The  PMHS strain patterns were compared to the THOR-NT strain patterns to evaluate if this instrumentation could be used for the development of an injury criterion.

This paper presented the first observations but more in-depth analysis is needed to draw conclusions. The approach is promising, but it was shown that some differences between PMHS and THOR will be difficult to correct. However, it still has to be defined if this is really a concern or not. To decide, THOR strain levels will have to be compared to PMHS rib fractures.

# ACKNOWLEDGEMENTS

# REFERENCES

Trosseille, X., Baudrit, P., Leport, T., Vallancien, G. (2008). Rib Cage Strain Pattern as a Function of Chest Loading Configuration. Stapp Car Crash Journal 52: 205-231.