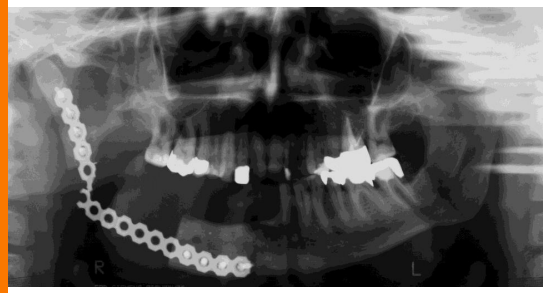
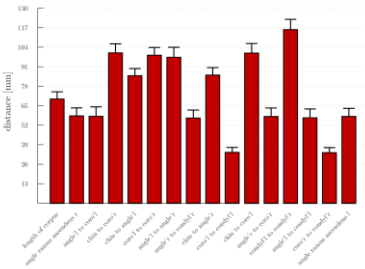
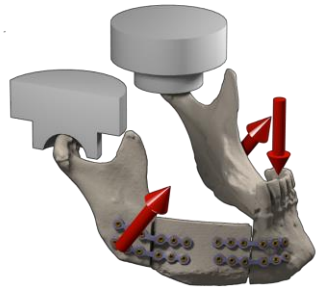
Robust optimization of osteosynthesis treatment of mandible fractures under consideration of inter-individual bone shape variations







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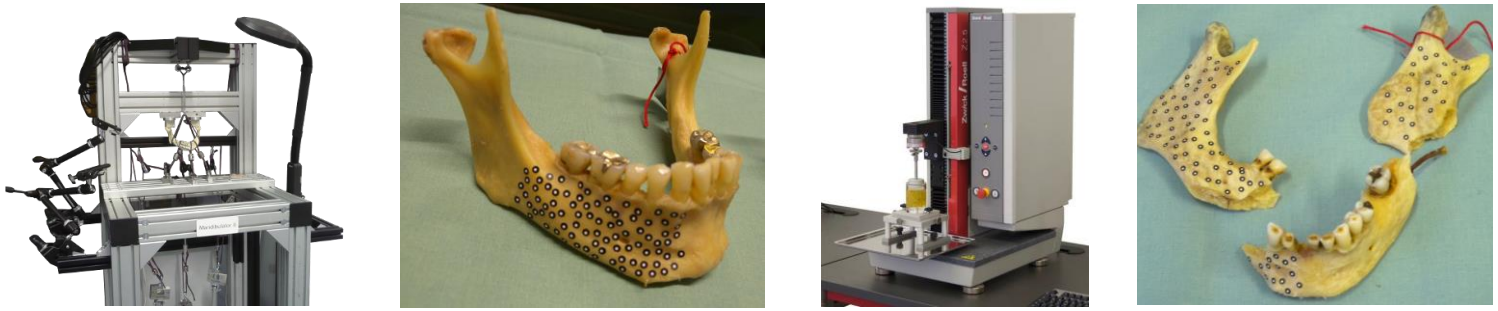
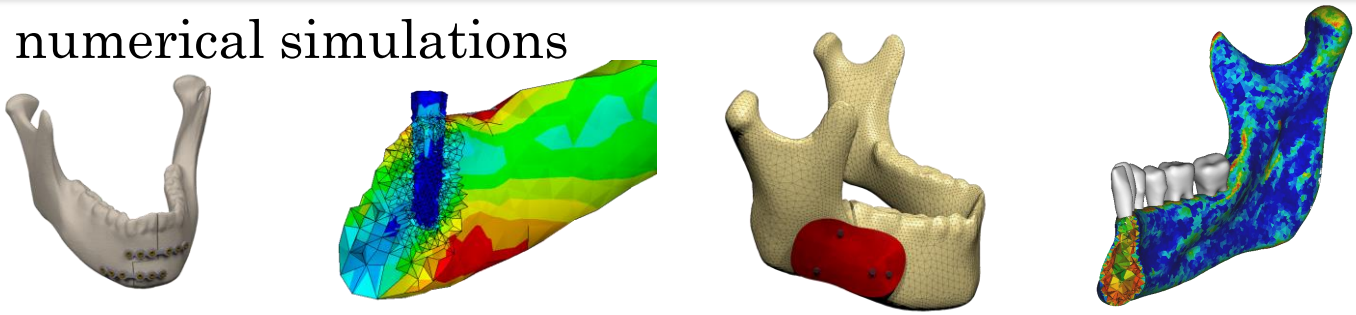
Ismaninger Straße 22
81675 München

Overview on the topics of the interdisciplinary research group

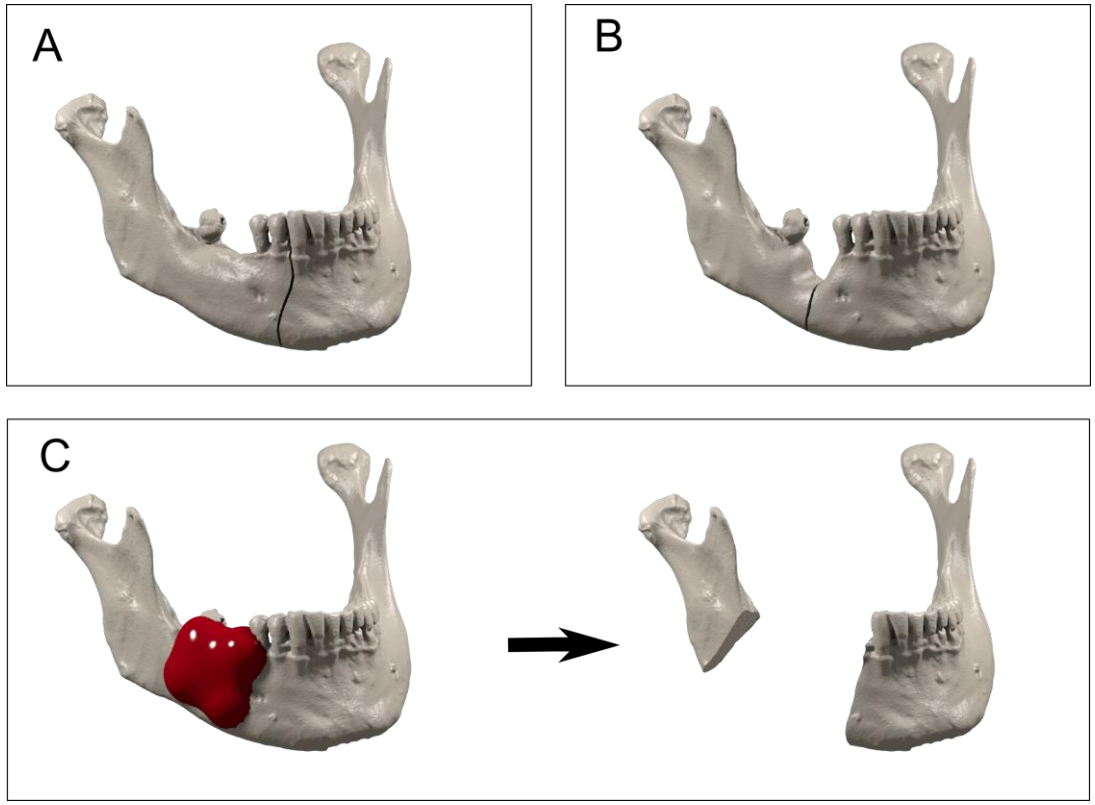
- Research in the dialogue between medicine and engineering sciences
  - biomechanical experiments



  - numerical simulations



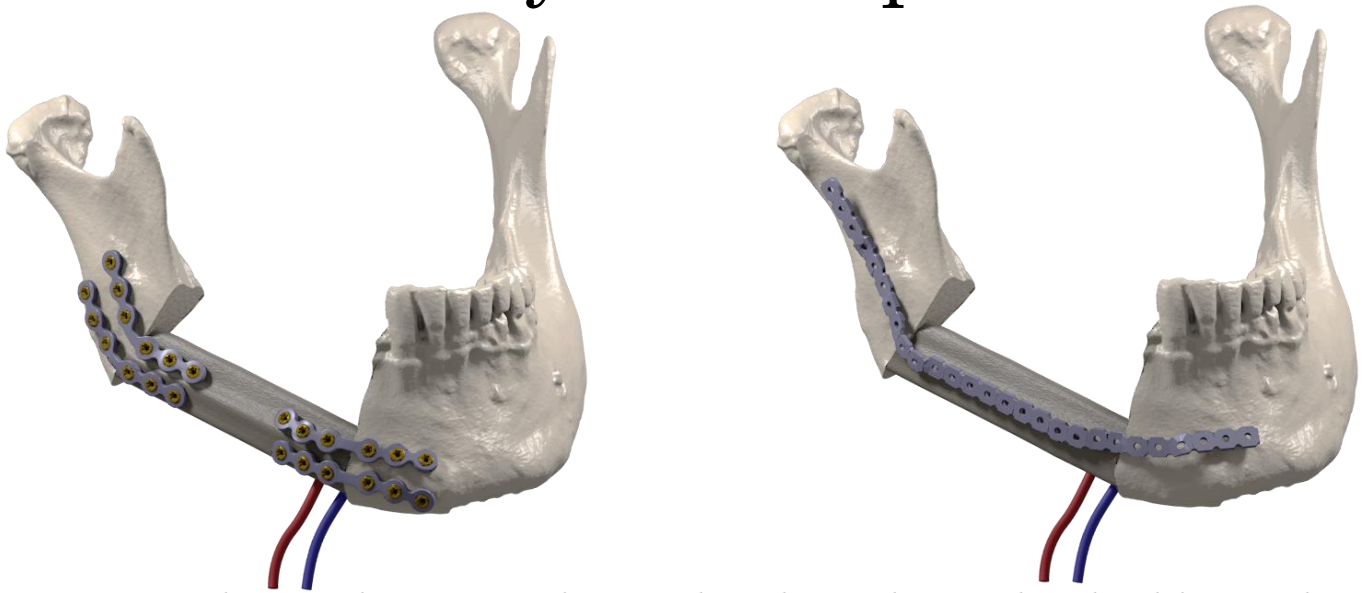
Indications for osteosynthesis treatments



- Mandible fractures (A) are stabilized with small osteosynthesis plates
- Cystic bone atrophy (B) or tumors (C) make bone removal necessary

-> In all cases stabilization of the fragments with plates is necessary

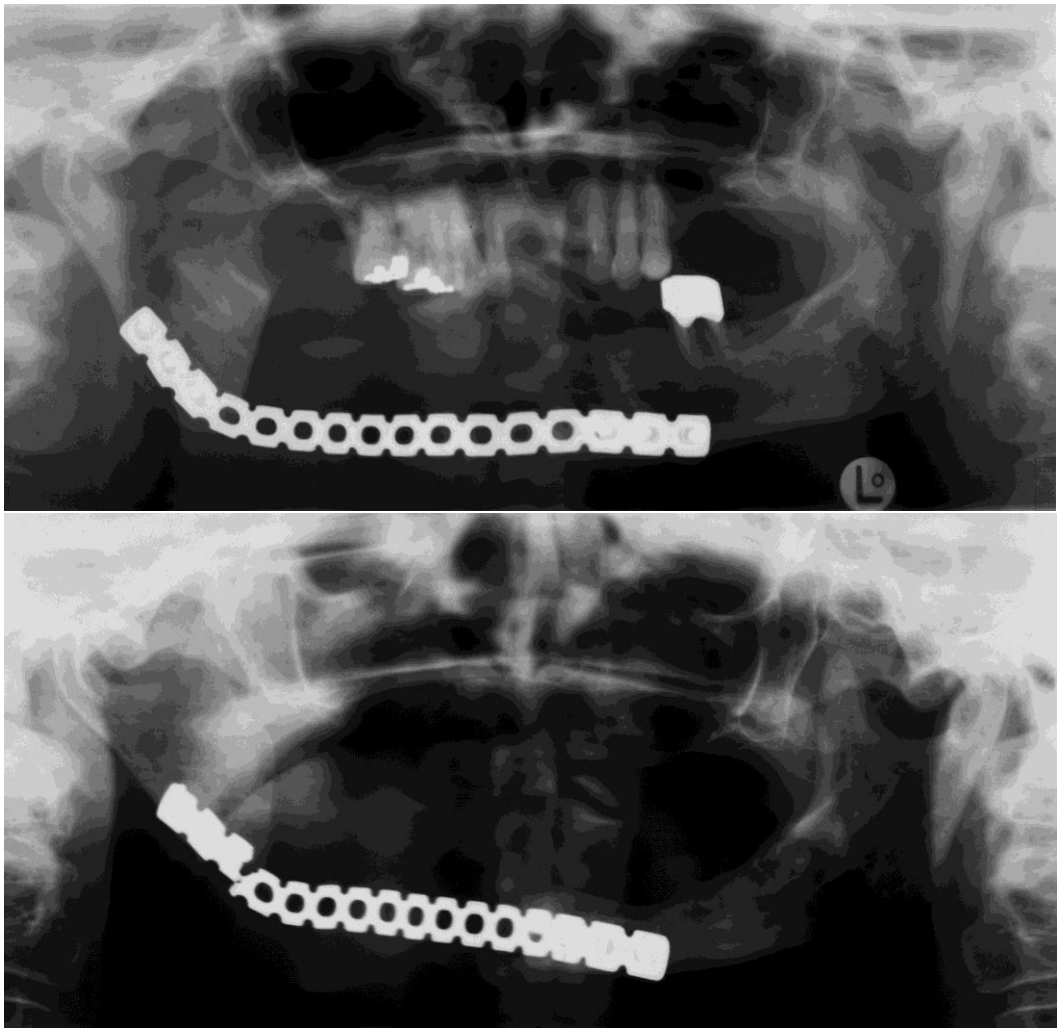
Reconstruction with bone transplants and osteosynthesis plates



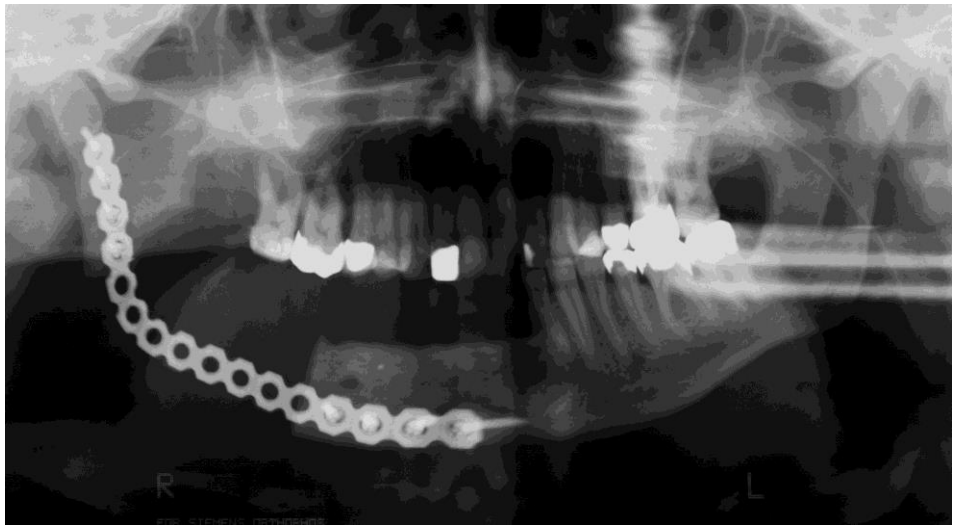
- Mini osteosynthesis plates may be easily adapted to individual bone shapes
- Bigger reconstruction plates are more difficult to adapt to individual shapes
- Plates are bent inter-operatively in a tedious and time consuming procedure
- Plastic deformations are weakening the material and may cause plate fractures when chewing forces are acting

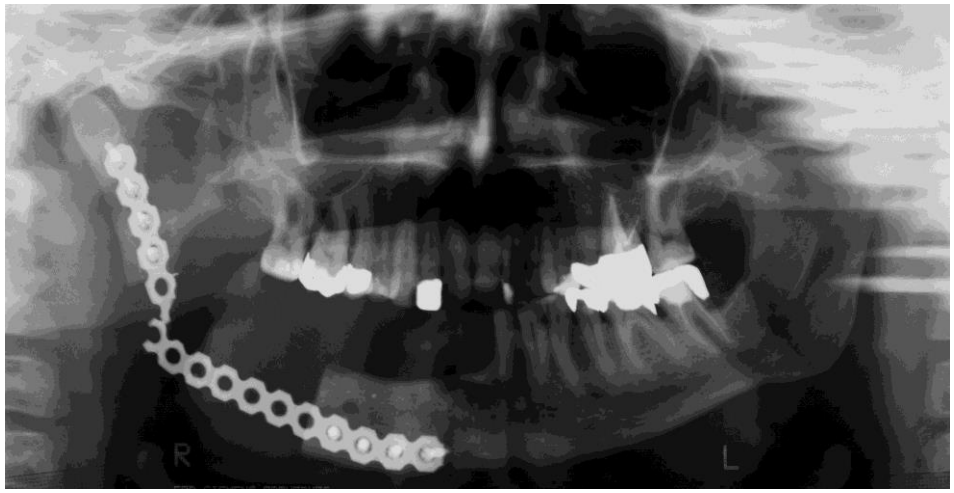
Optimization of plate geometry is necessary !

Clinical problems: plate factures

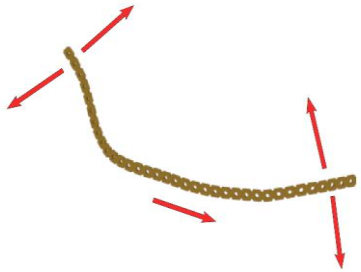


Clinical problems: plate factures





Parameterized variation of plate shape



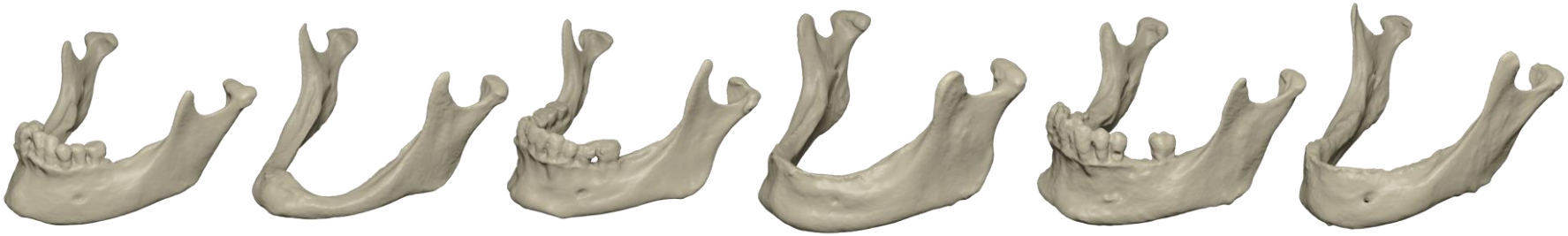
The shape of plate can be desrcibed by parameters and used in an optimization to find the best match between plate and bone surface

Parameterized variation of plate shape

Shape of plate can be optimized to find the best match between plate and bone surface

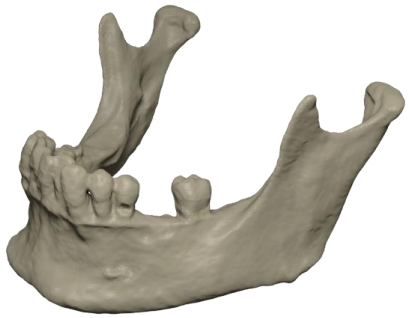
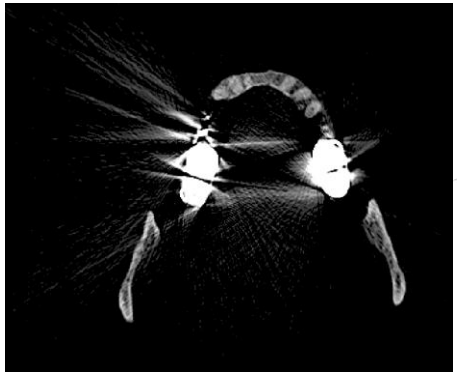
Problem Setting:

explicit variability of the shape of the mandible bone in between different patients



- Complex shape of the mandible bone
  - Several parameters are necessary to describe its shape sufficiently
  - Geometric evaluations are more difficult than at the simpler shaped tube bones in orthopedics
  - Evaluations should be standardized and reproducible
    - large data sets make automation necessary

Data base of the study presented here: 65 human mandibles

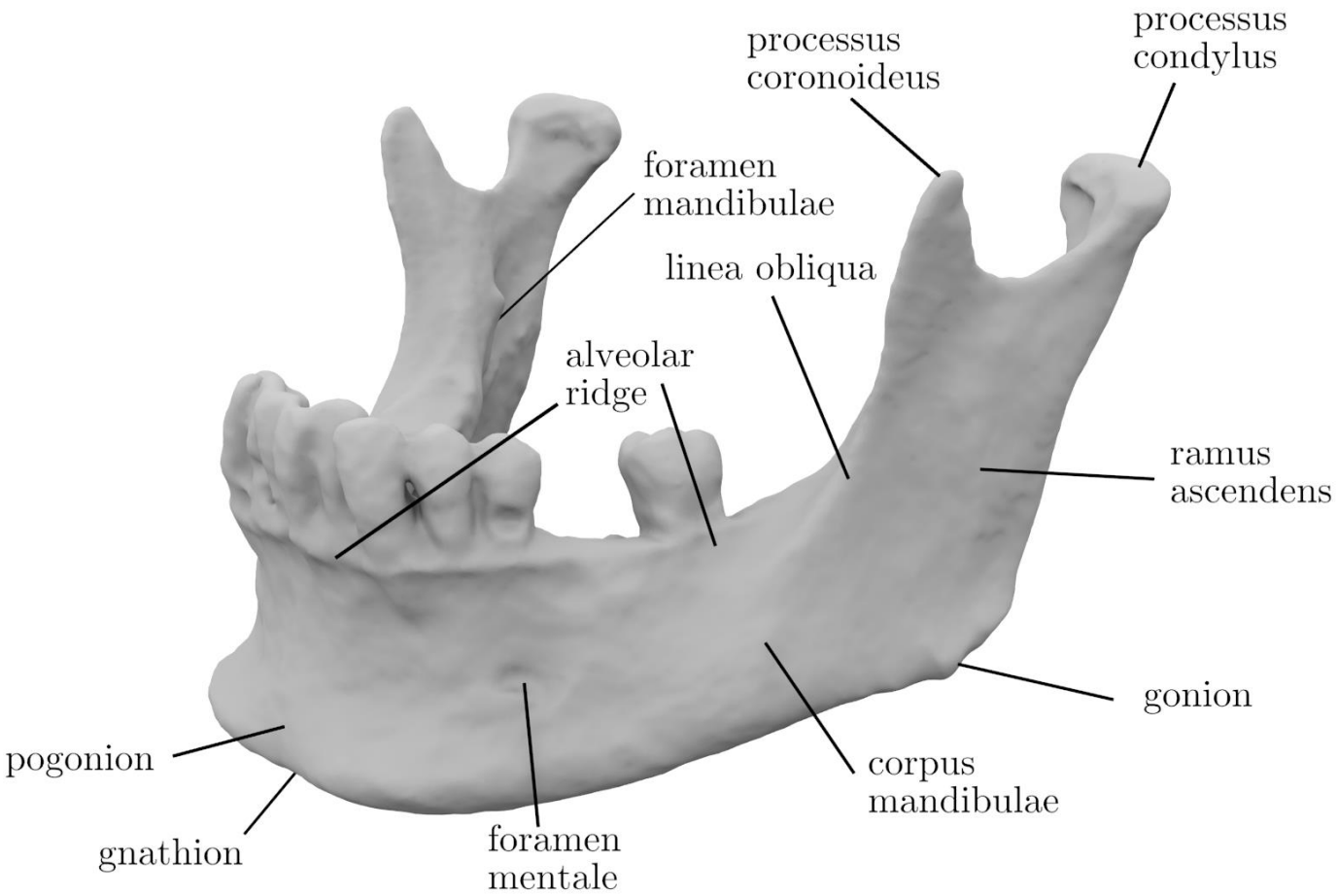





- Volumetric images of CT scans
  - Resolution 0,35 x 0,35 x 0,33 mm
- Semiautomatic segmentation
  - Artifacts due to metallic structures need to be removed manually
- Geometric assessment is fully automated

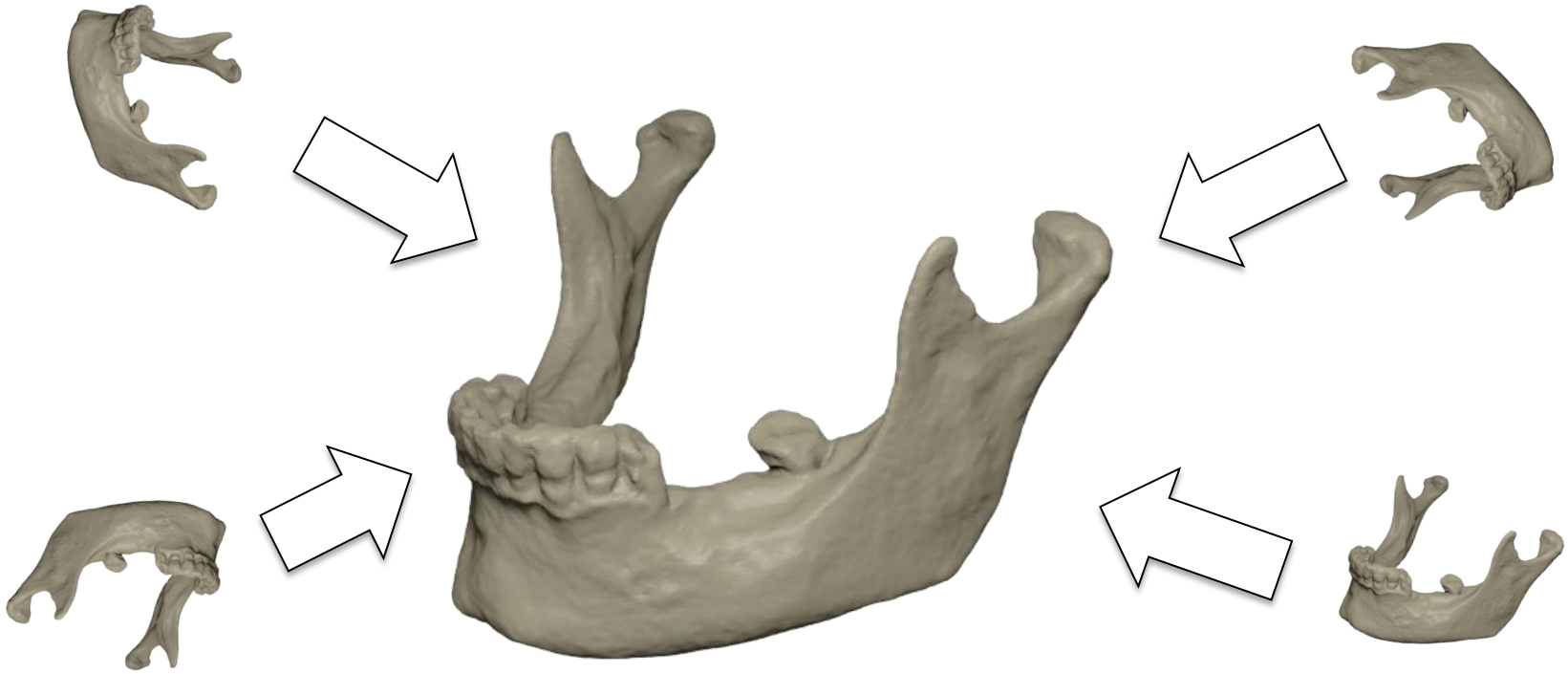
Parts of this work have been presented at the conference „AK Kiefer 2012“

Reference: S. Raith T. Steiner, T. Torsiglieri, A. Füglein, F. Hölzle : Vorstellung einer digitalen Datenbank basierend auf CT Aufnahmen von 65 humanen Unterkiefern zur Erstellung von standardisierten Modellen für numerische Simulationen, 62. Jahrestagung der Arbeitsgemeinschaft für Kieferchirurgie, 17.-18. Mai 2012 Bad Homburg

Characteristic anatomical points on the mandible



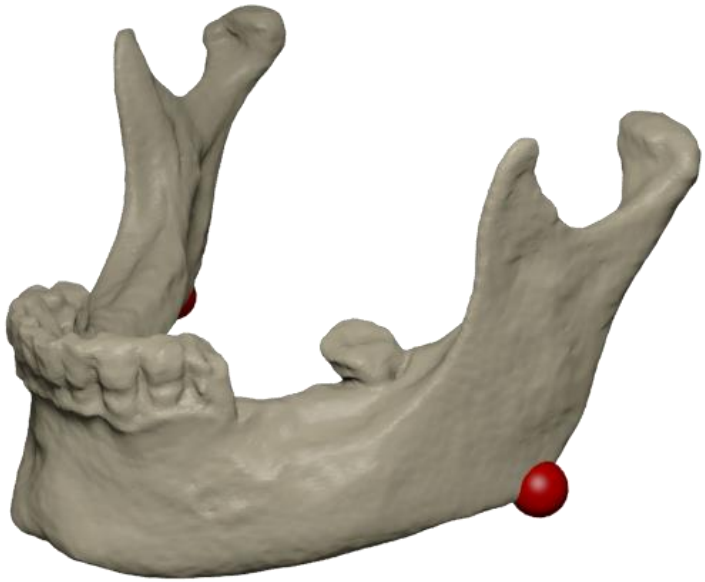
Introduction of the automated algorithm



Evaluation is fully automated on the computer

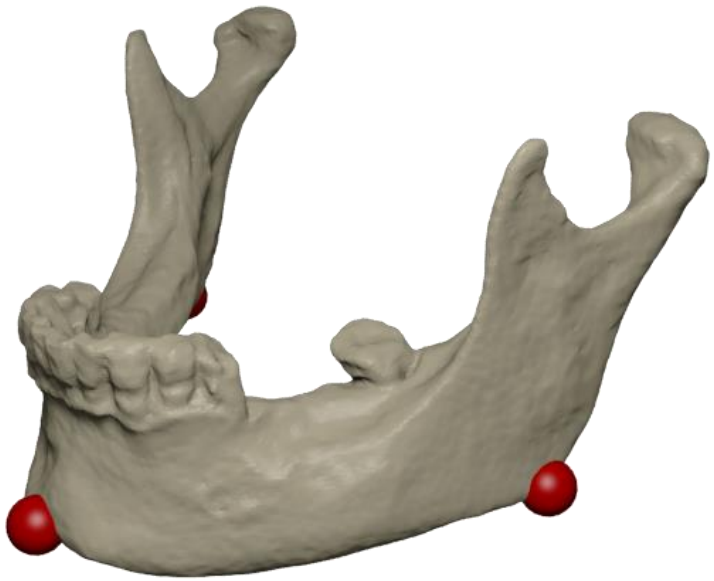
- hence there is no observer variability
- arbitrary initial orientation in space is possible

Landmark Detection



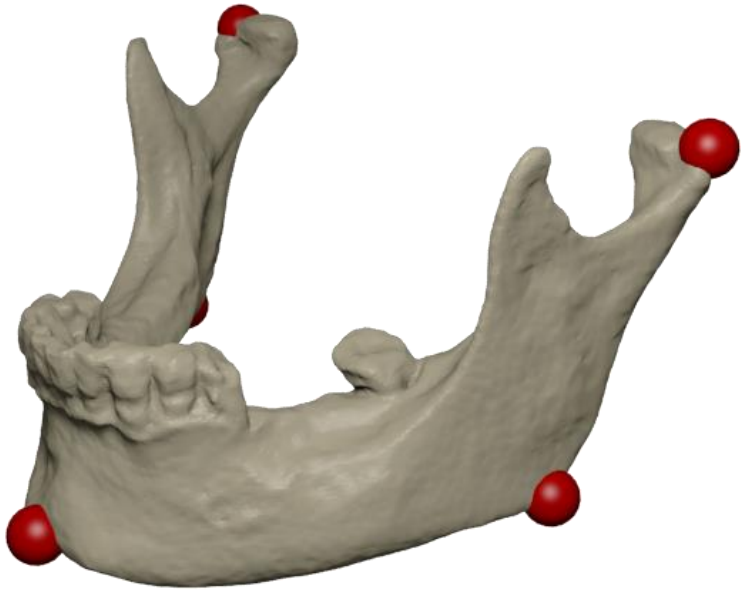
Mandibular angles are automatically detected.
defined as maximal *posterio-caudo-lateral* point

Landmark Detection



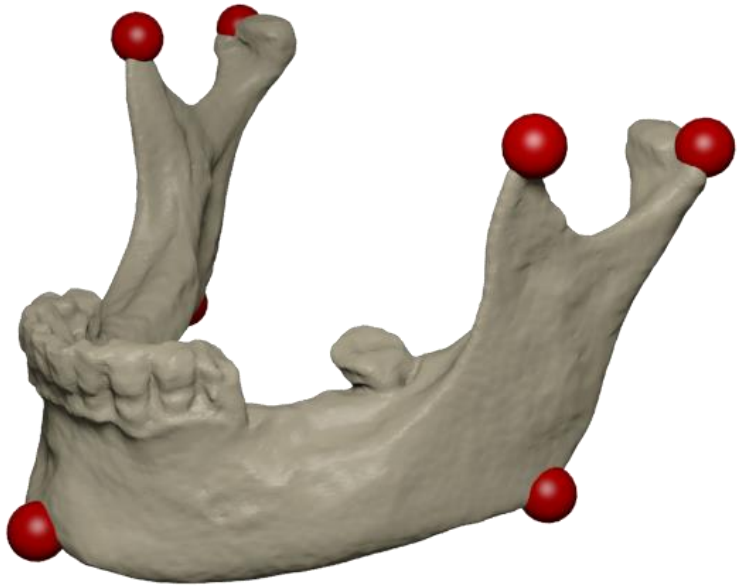
Position of pogonion
defined as maximal *anterior* point
in the median plane

Landmark Detection



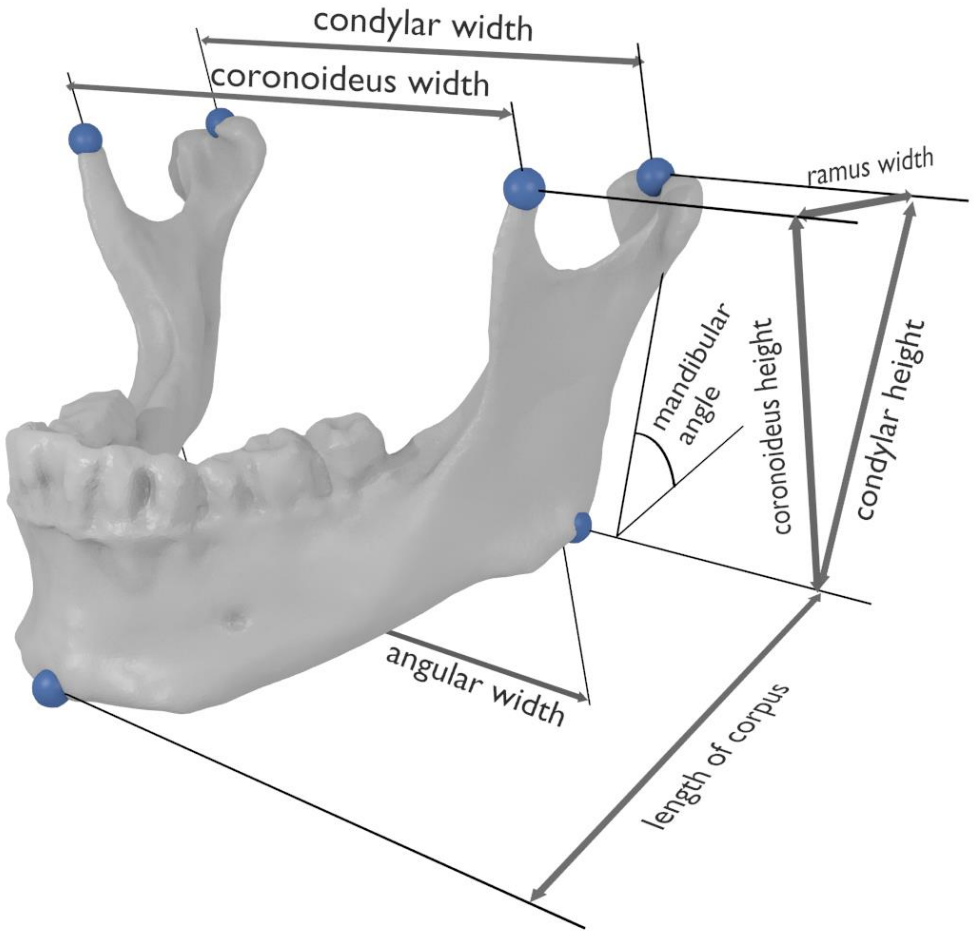
Tips of the condyloid processes
defined as maximal *posterio-cranio-lateral* points

Landmark Detection



Maximal projection in *cranial* direction
(confusion with condyloid processes is excluded)

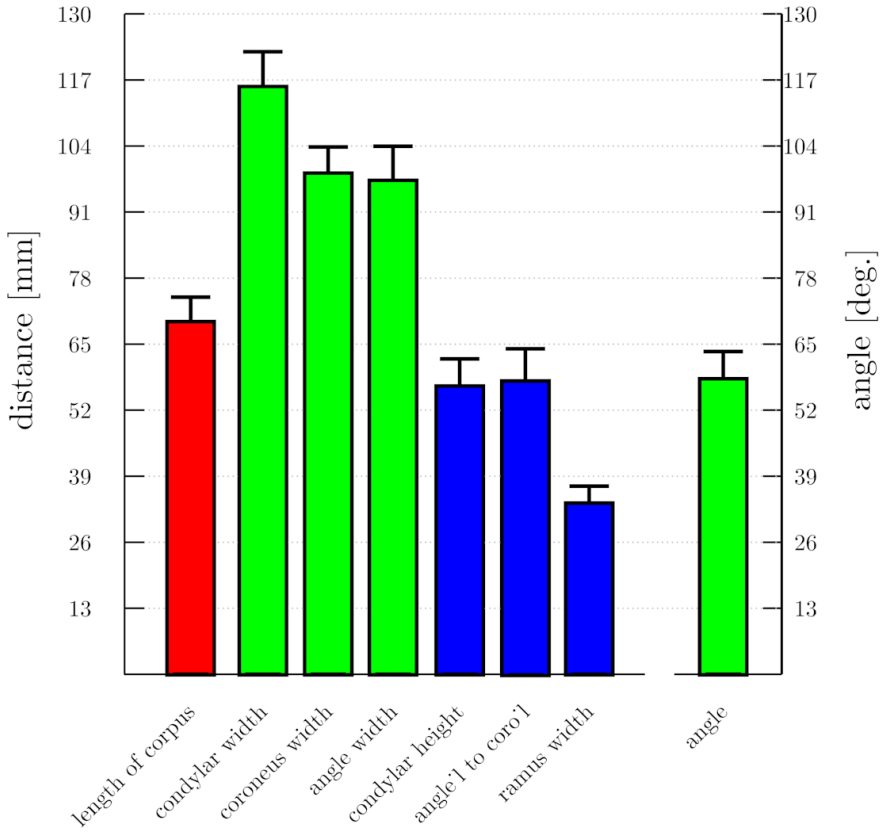
Distances are used for statistic evaluations



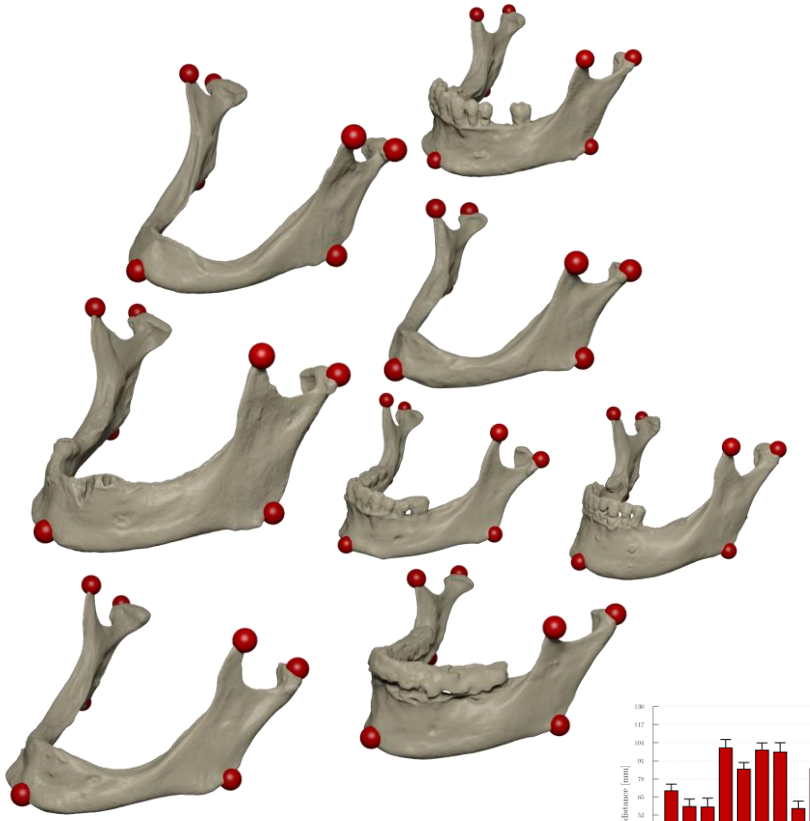
- Width:
  - inter condylar
  - inter coronoidal
  - inter gonional
- Ramus ascendens
  - gonion to condyle
  - gonion to p. coronoideus
  - Ramus width (gonion to condyle)
- Length of corpus
  - gonion to pogonion
- Angles between ramus ascendens and corpus mandibulae

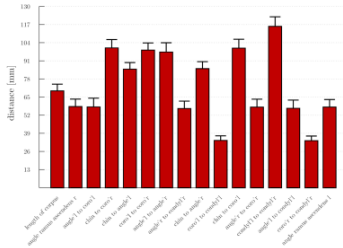
Statistical evaluations:

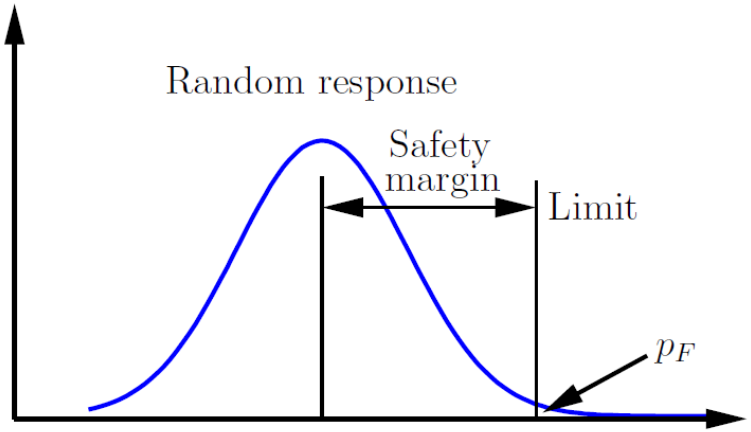
means and standard deviations may be calculated



Interpretation of anthropometric variation as scattering input parameters







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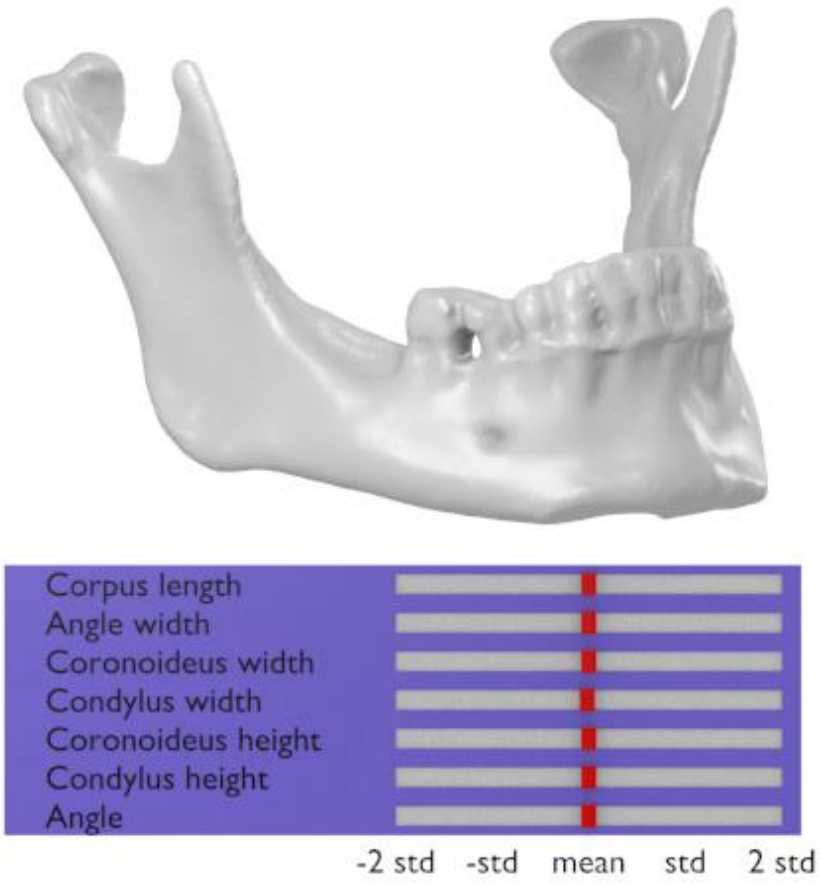
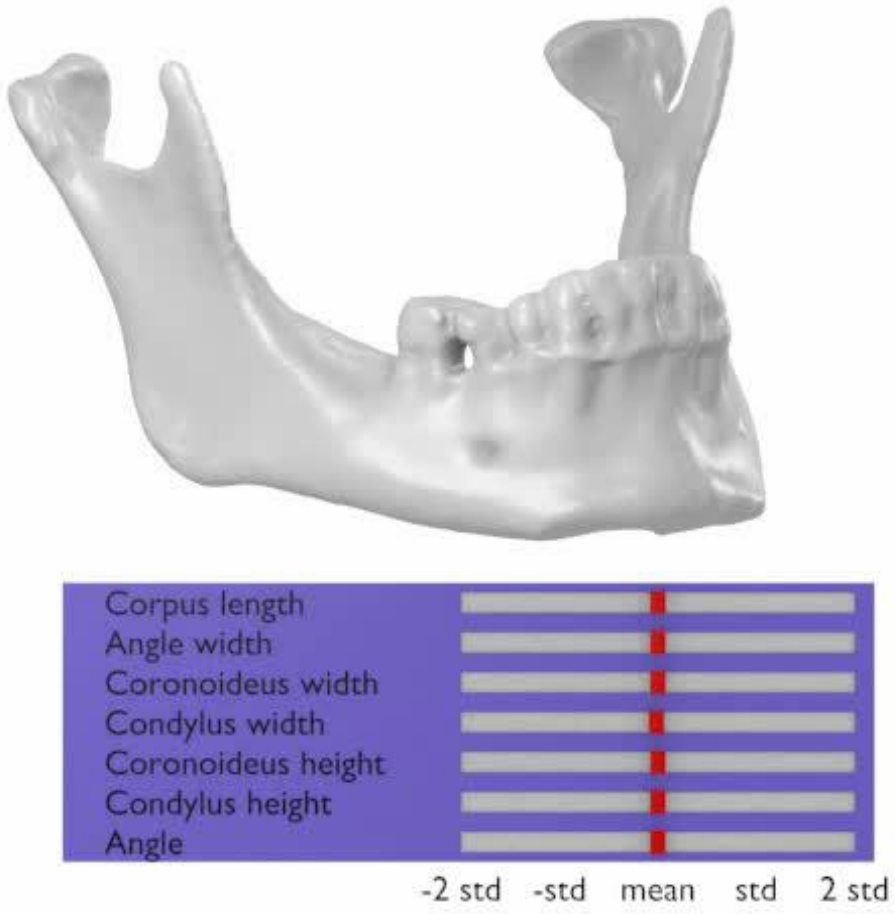


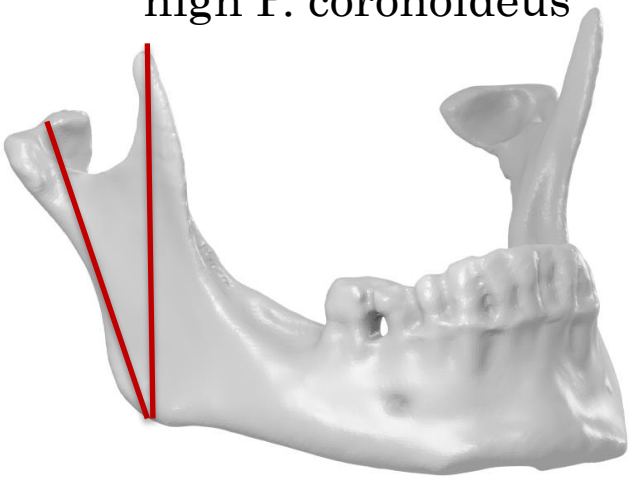
- In Blender a possibility for user interaction was implemented to provide direct access to all possible deformations (Programming language Python)
- Standard deviations are shown for the purpose of orientation

Interpretation of anthropometric variation as scattering input parameters

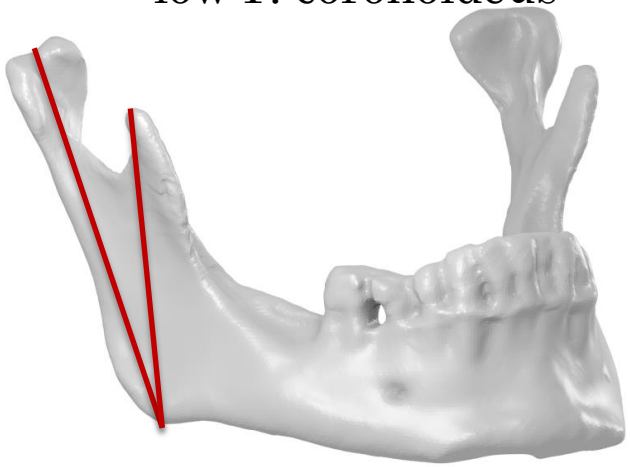


Extreme combinations of simple shapes

low P. condylus
high P. coronoideus



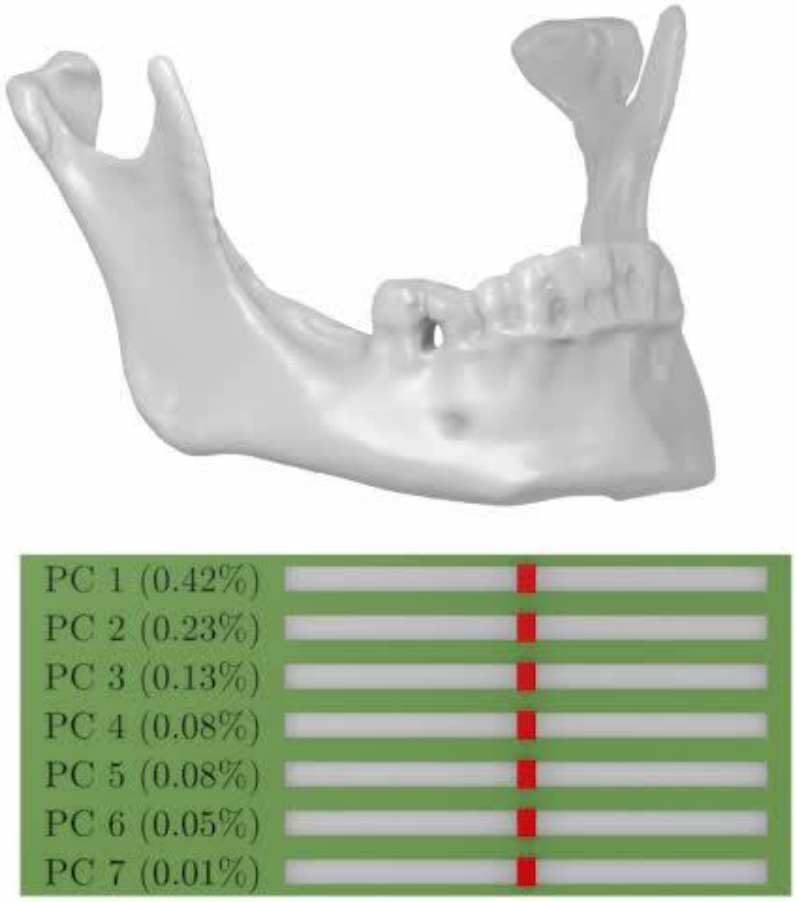
high P. condylus
low P. coronoideus



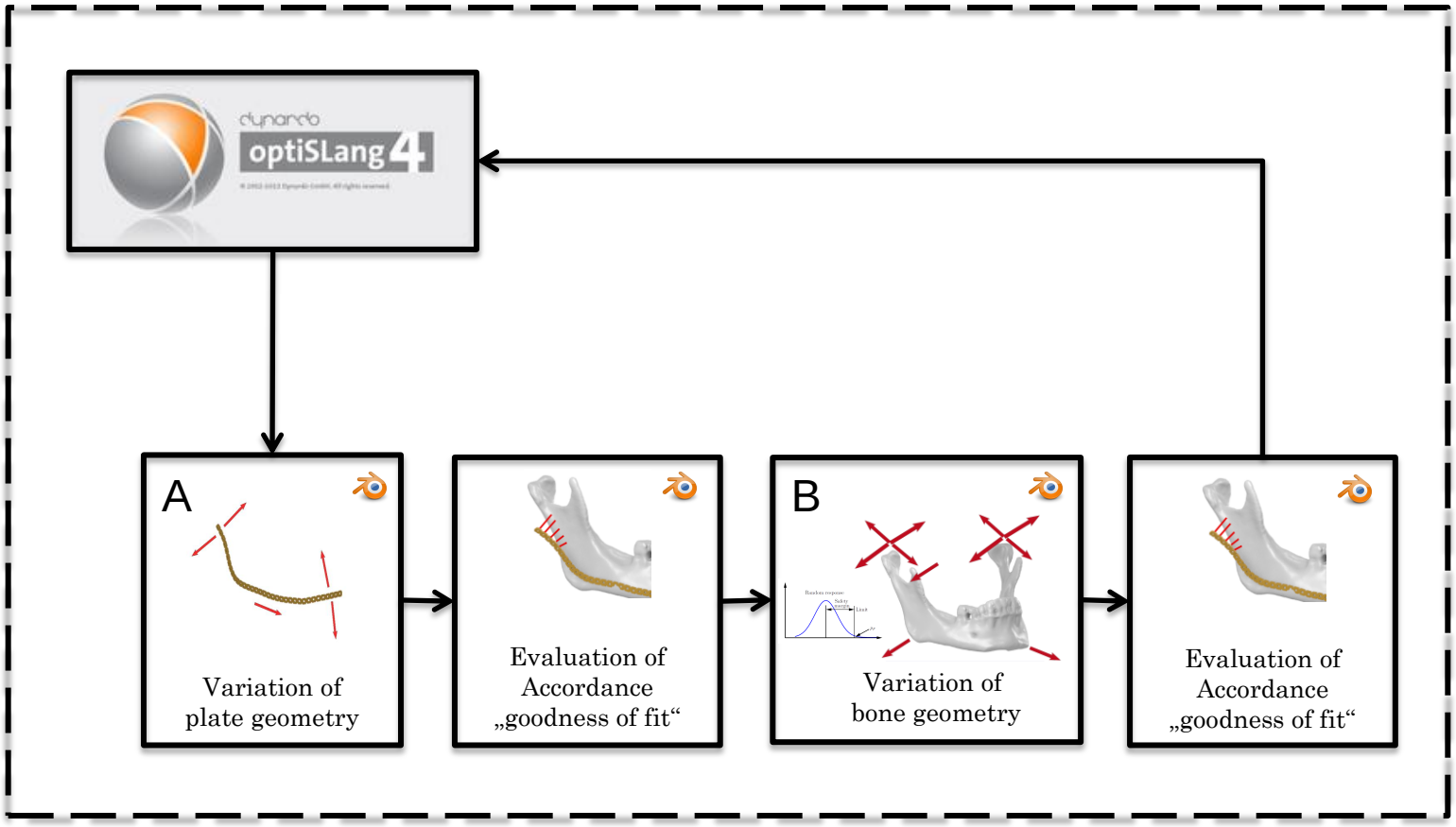
Shapes are not statistically independent!!

-> covariance and principle component analysis

Principle component visualization



Robust optimization work flow

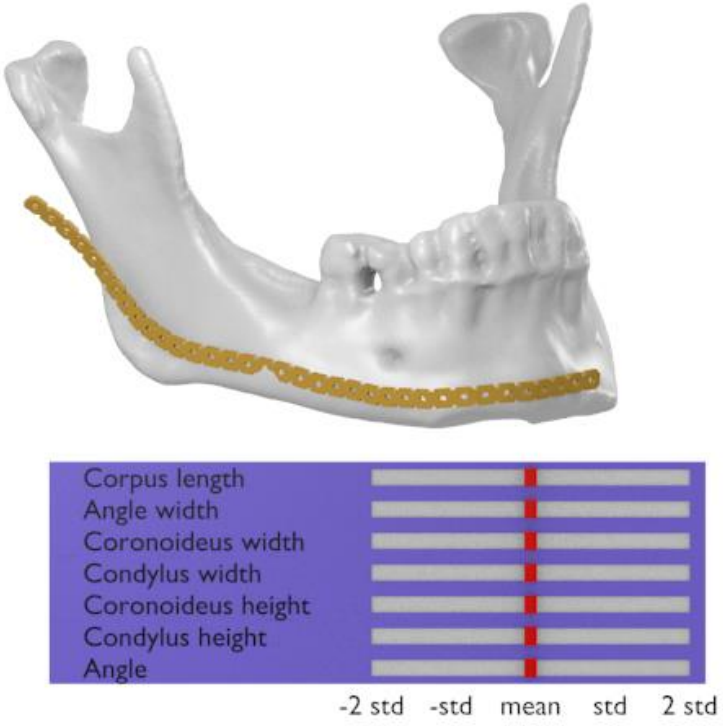


A) Design variable variations that define the plate geometry

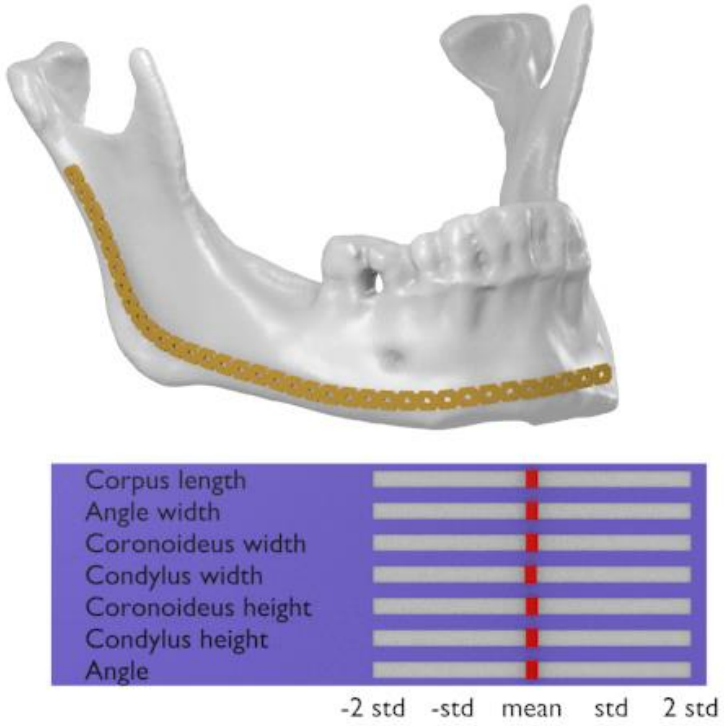
B) Stochastic variations in bone shapes

Objective: geometric accordance between plate and mandible

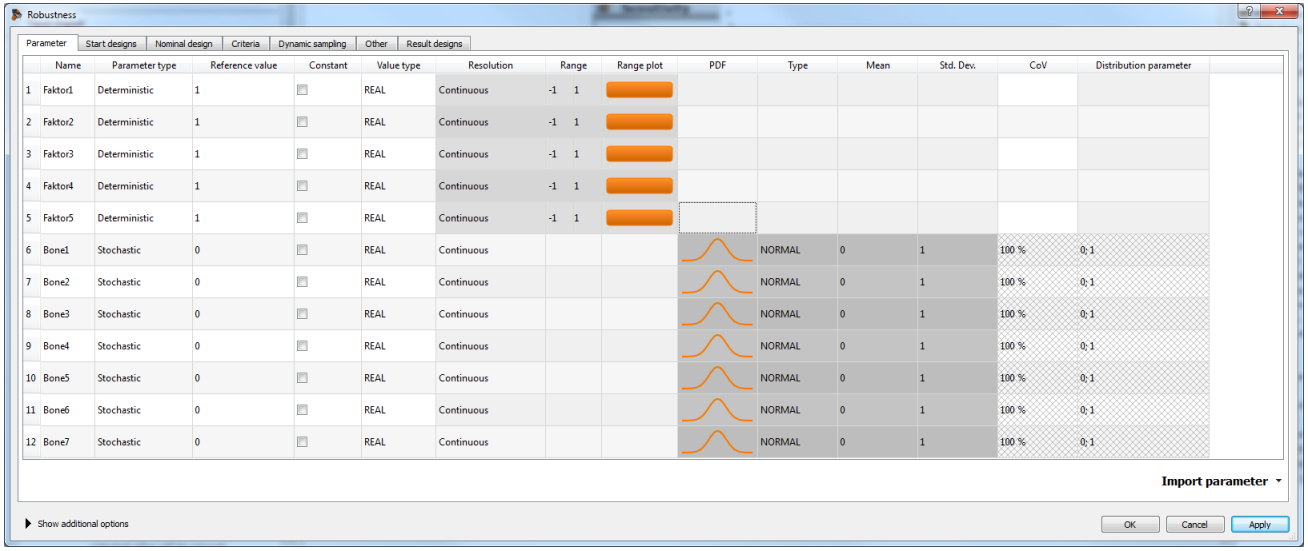
bad fit of the plate

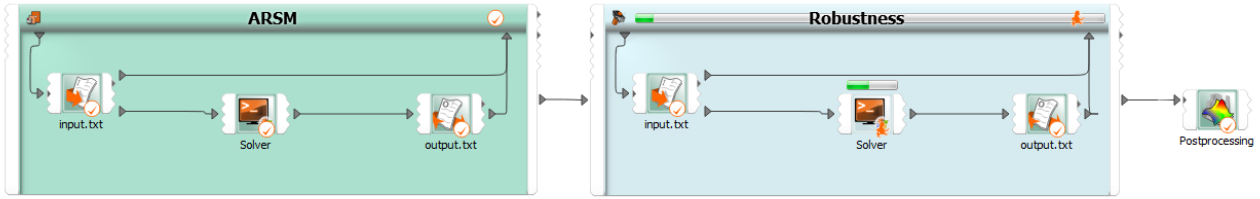


good fit of the plate



Results of sensitivity analysis and robustness evaluation

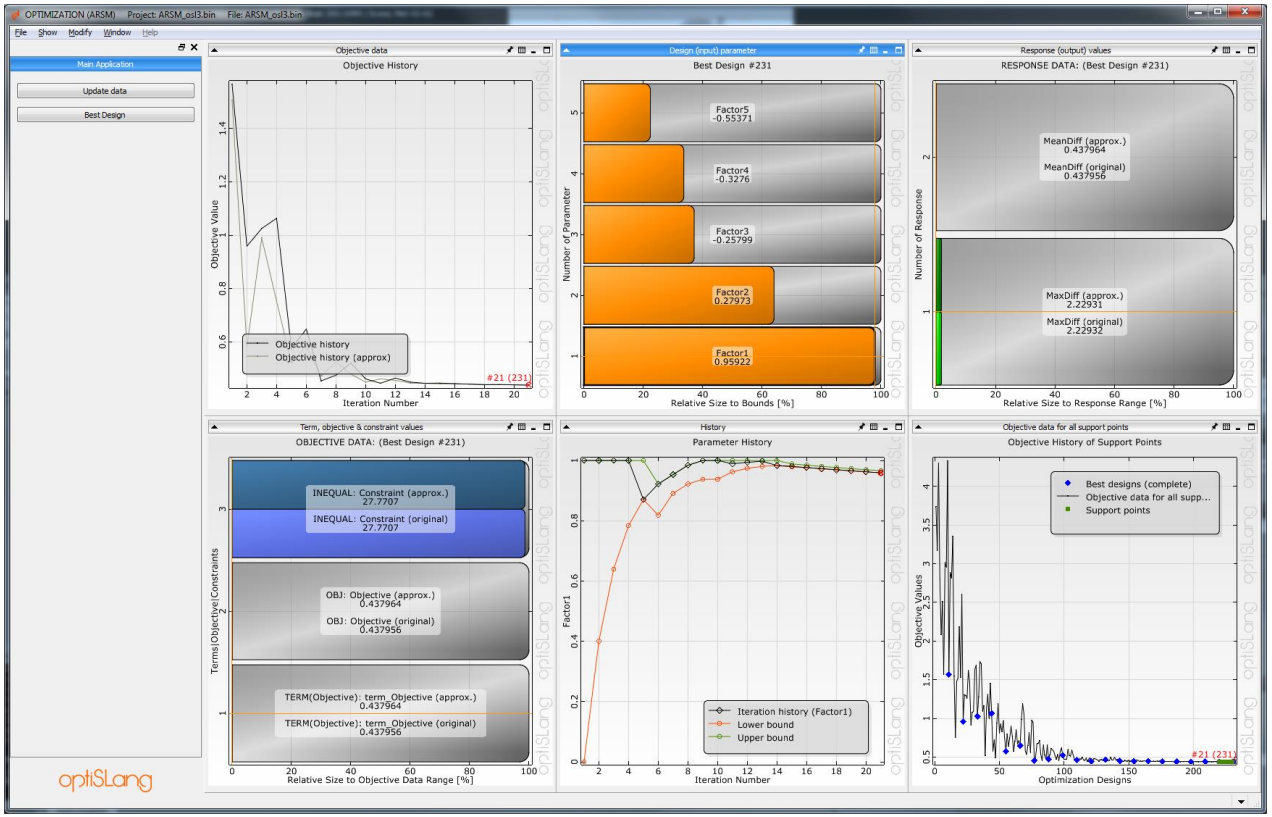




5 design variables for the plate geometry

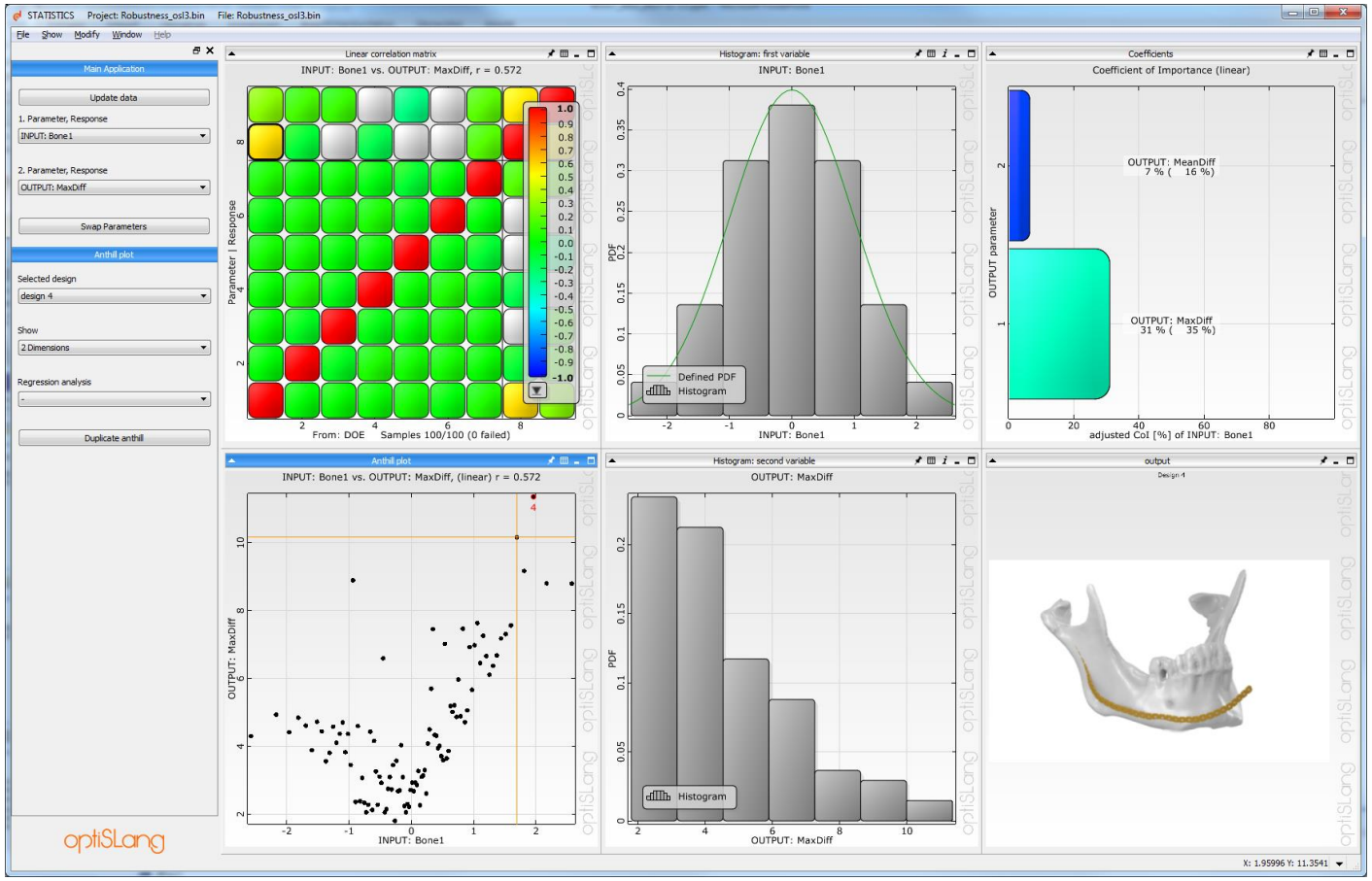
7 stochastic variations of the bone geometry

Results of ARSM optimization



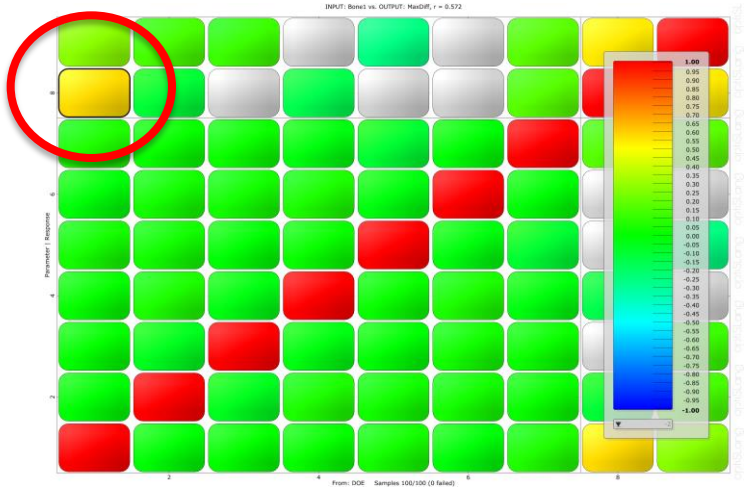
Defined optimal shape of the osteosynthesis plate suited to the mean mandible shape could be found.

Results of the robustness evaluation



example image: extremely short mandible with bad fit of the plate that was optimal for the mean population

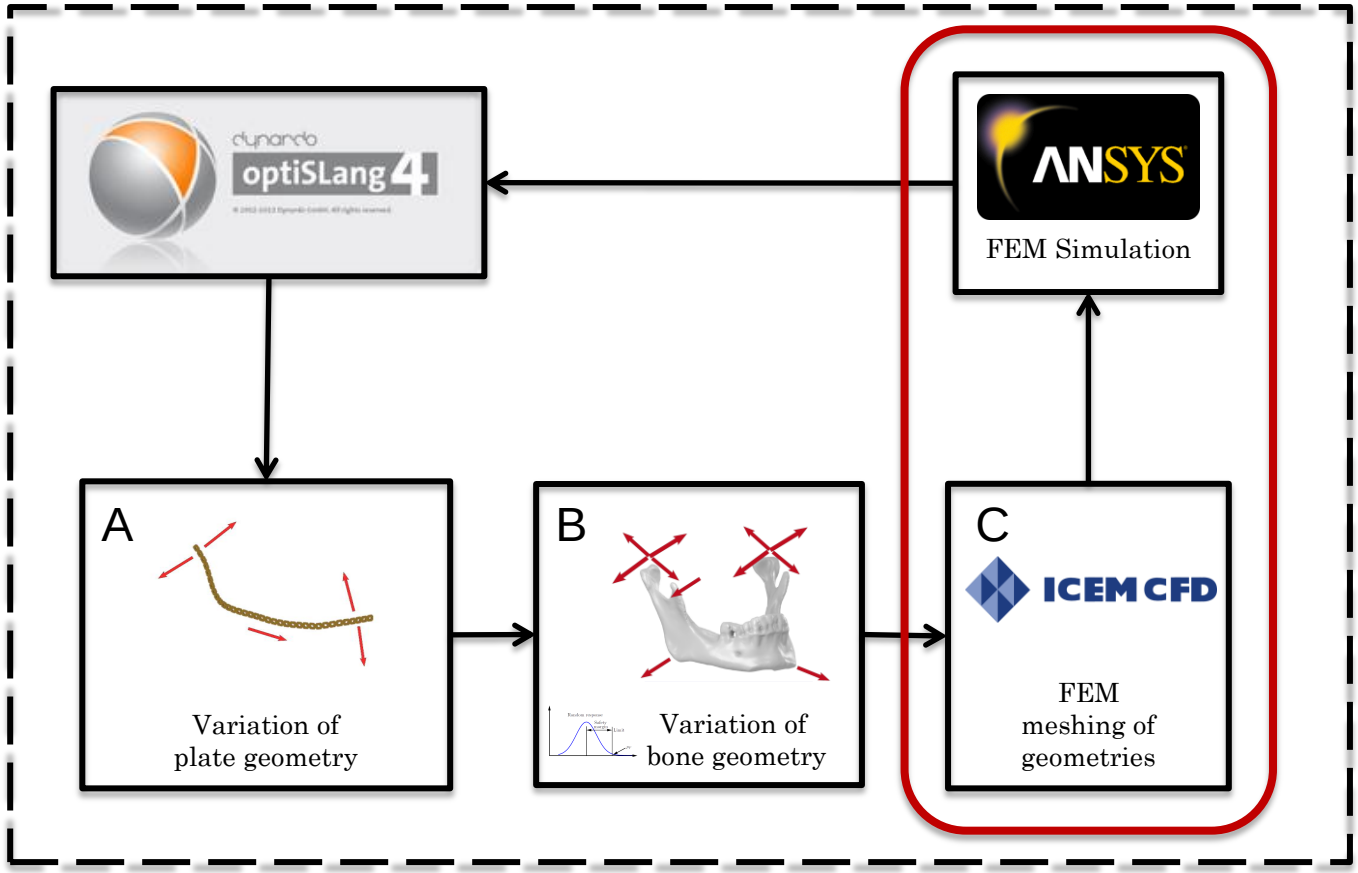
Results of sensitivity analysis and robustness evaluation



- Most influential parameter is the variation in mandible corpus length

Thus the corpus length is the parameter that has most importance and may be the only one that needs to be considered when thinking about confection sized osteosynthesis plates

Outlook: Robust optimization work flow with FEM in loop

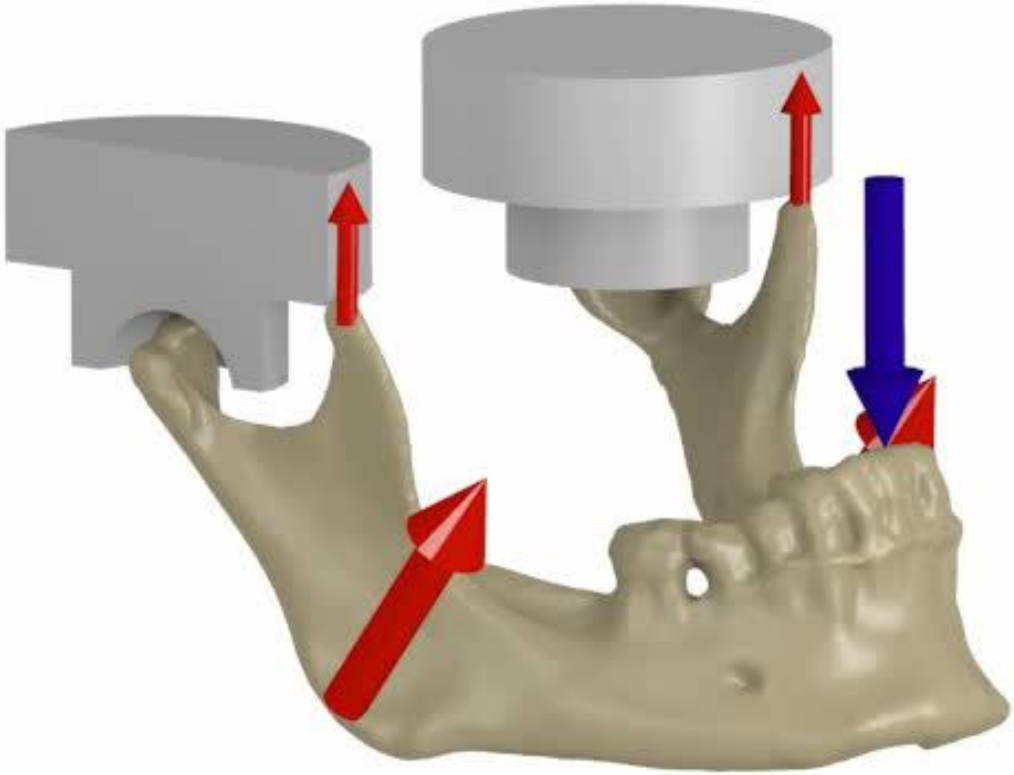


A) Design variables that define the plate geometry

B) Stochastic variations in bone shapes

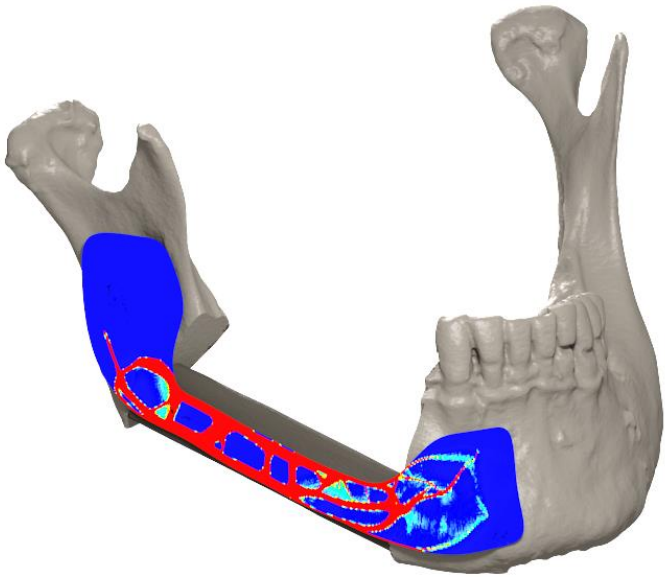
C) Use of finite element simulation within the loop

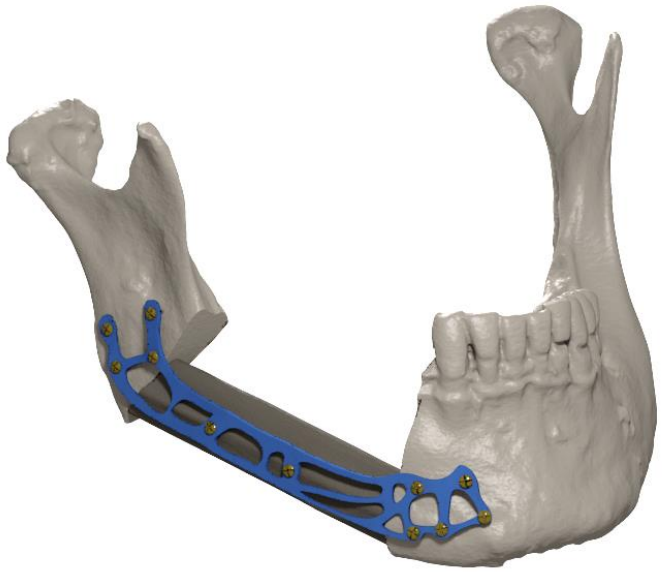
Outlook: Mechanical Simulations in the presented process chain



Variation in bone geometry is essential for the biomechanical boundary conditions and the resulting stress distributions

Outlook: more complex plate shapes

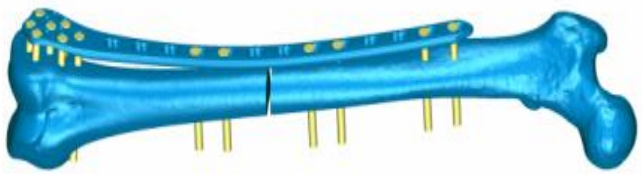


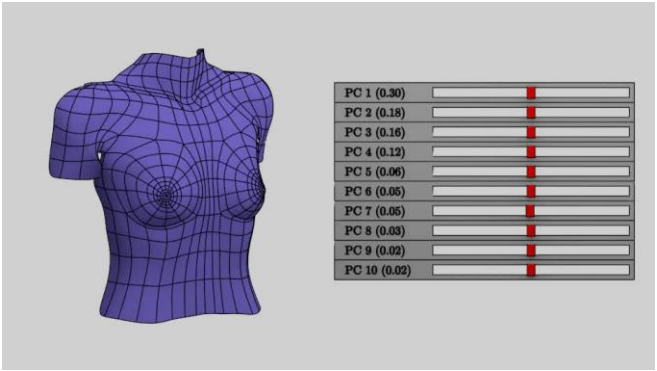


- More complex shapes of osteosynthesis plates may be developed
  - e.g. with topological optimization
- Individualized for very special cases
- Rapid manufacturing technologies may be used to produced optimal shapes

Conclusions and Outlook

- Robust Design Optimization is valuable in biomechanics
- Multimodality data interpretation (confection sizes S, M, L, XL …)
- Further applications of the presented approach
  - other medical applications (orthopedics, trauma, plastic surgery)





  - garment industries
  - ergonomics (tools, car seats…)
  - sports industries

Thank you for your attention

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