Application of finite element method for the analysis of a prefabricated post-and-core – tooth system

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In recent years in the area of prosthetic treatment, great emphasise was put on leaving a residual dentition inside mouth. In a teeth after endodontic treatment or with broken crown a healthy root is a natural implant that can be used for further reconstruction. Use of posts-and-cores is one of possible methods of widely damaged tooth crowns treatment. There is a lot of different types of prefabricated posts-and-cores. Numerical analysis of the prefabricated post-and-core – tooth system was conducted by the authors. The prefabricated Flexi-Flange post-and-core from the Essential Dental System was selected for the analysis. The scope of the analysis has covered calculation of displacements, strains and stresses in each elements of the analysed system – depending on the applied post material and load applied on the prosthetic crown. The analysis reviled that there is a significant influence of the type of the post material and load on results. It was found that the most unfavourable variant of load is the one with force applied on the labial surface at the angle of 45° to the axis of the tooth. The results of the analysed system provided a valuable guidelines for proper design of its form, geometrical properties, selection of the mechanical properties and the optimal strengthening degree of metallic biomaterial.

Key words: prefabricated posts, prosthetic reconstruction, finite element analysis

Introduction

In teeth after endodontic treatment or with damage tooth crown, a healthy root is a natural implant that can be used for the further reconstruction. One of tooth' crown reconstruction methods is the use of posts-and-cores, that increase the fill retention and at the same time should retain physiological way of forces transfer generated during mastication. Because of the fabrication method restorations can be divided into the individual casts and the prefabricated posts. In the case of the prefabricated posts the effectiveness of prosthetic rehabilitation equally depends on geometric form and material properties of post as well as the adaptability to the body environment [1,2].

Nowadays, there is a lot of different types of posts-and-cores available off-the-shelf. The diverse construction, and material from which they are produced, caused different work of biomechanical post-and-core – tooth system depending on the applied posts. It causes a natural need to widely understood studies on biomechanics of prosthetic restoration with the use of posts-and-cores. The finite element method is the most commonly used for this purpose. On the basis of literature review it has been observed that there is a lot of problems in that field. Researchers have worked on inter alia: stresses in posts depending on the applied dental cements during jaw clenching [3], while others have studied the stress distribution in structures surrounding the post [4]. Despite of many works about strength analysis of posts-and-cores with the used of FEM, it was observed that the results of researches aren't consistent. In addition, the analysis included simplified models of posts-and-cores – tooth system. Periodontium, cancellous bone and cortical bone were omitted in the analysis, what has a major impact to imitation of phenomena occurring in the real post – tooth system [5, 6]. Therefore it was decided to make the numerical analysis of post-ad-core – tooth system taking into account real phenomena in the stomatognathic system.

Material and method

The prefabricated Flexi-Flange post from the Essential Dental Systems, Inc. (Size 2) was analysed. This post was selected because it provides high retention and low pressure on the root wall. In addition, it has a flange, that ensures the sustainability of the restoration, a larger contact area and a good maintenance and interception of occlusal loads. In the first stage of the analysis the post-and-core geometrical model was created in Autodesk Inventor – Fig. 1. Next, geometrical model of the post-and-core – tooth system was developed. The system consisted of: root, prosthetic crown, reconstruction of the stump, cement, gutta-percha, periodontium, cancellous bone and cortical bone – Fig. 2. The lower root canine model with fully reconstructed crown was analysed. For these models, in order to perform the calculation by the finite element method, the mesh was generated.

The ANSYS Workbench v13 software was used for elements discretization – Fig. 3. Discretization was realized with the use of the Solid 187 element.

To carry out calculations it was necessary to evaluate and establish initial and boundary conditions which imitate phenomena occurring in the real system with an appropriate accuracy. The following assumptions were made:

- the crown was loaded with the force F = 300 N exerted on the incisal end (I variant) and on the labial surface at the angle of 45° to the axis of the tooth (II variant),
- for both load variants, the positioning of the supports' constraints (on the cortical bone) preventing the movement along X, Y and Z directions.

In the numerical calculation material data of model components available in a professional literature and manufacturers data (Table 1) was taken into account.

The analysis included determination of displacements, strains and stresses in elements of the analysed system.

Results

The results of the analysis were presented in Tab. 2-5 and in Fig. 4-6. On the basis of the results, influence of the applied force on the obtained values of displacements, strains and stresses in elements of the analysed system was determined. The largest displacements, strains and stresses occurred when the system was loaded on the labial surface at the angle of 45° to the axis of the tooth – Tab. 1 and 2, Fig. 4-9.

Analysis of results performed for the post-and-core – tooth system revealed that higher values of considerated parameters were observed for the II variant regardless of the post material.

The maximum values of total displacements were registered for crown (II variant) both for the post made of Cr-Ni stainless steel and Ti6Al4V ELI alloy and were equal to $\Delta l = 0.30$ mm. The highest equivalent strains were observed for periodontium (II variant) for the post made of Cr-Ni steel and were equal to $\varepsilon_{max} = 32\%$. Highest equivalent stresses were found for the post made of Cr-Ni stainless steel (II variant) and were equal to $\sigma_{max} = 460$ MPa. The highest shear stresses were determined for II variant and were respectively: $\tau_{xy} = 80$ MPa for the post made of Cr-Ni stainless steel, $\tau_{yz} = 25$ MPa in the crown – for the post made of Cr-Ni stainless steel and Ti6AL4V ELI alloy, $\tau_{xz} = 40$ MPa for the post made of Cr-Ni stainless steel.

For the post-and-core (made of Cr-Ni stainless steel) – tooth system, the maximal total displacement was registered for the crown and it was: $\Delta l = 0.09$ mm i $\Delta l = 0.30$ mm for variants I and II respectively. The lowest total displacement was registered for the gutta-percha and was equal to $\Delta l = 0.01$ mm both for I and II variant. The highest equivalent stains were observed for the periodontium and were equal to: $\varepsilon_{max} = 13\%$ (I variant), $\varepsilon_{max} = 32\%$ (II variant). The lowest values of equivalent strains were equal to $\varepsilon_{max} = 0.02\%$ and were localized in the crown (I variant) and the gutta-percha (II variant). The highest values of equivalent stresses were localized in the post: $\sigma_{max} = 185$ MPa (I variant), $\sigma_{max} = 460$ MPa (II variant), while the lowest ones were observed for the gutta-percha: $\sigma_{max} = 0.10$ MPa (I variant), $\sigma_{max} = 0.25$ MPa (II variant). In addition, the shear stresses were investigated in each element of the analysed system:

- the maximal τ_{xy} were localized for the post and were equal to: $\tau_{xy} = 25$ MPa (I variant), $\tau_{xy} = 80$ MPa (II variant). The minimal τ_{xy} were localized in the gutta-percha $\tau_{xy} = 0.06$ MPa (I variant) and the reconstruction of

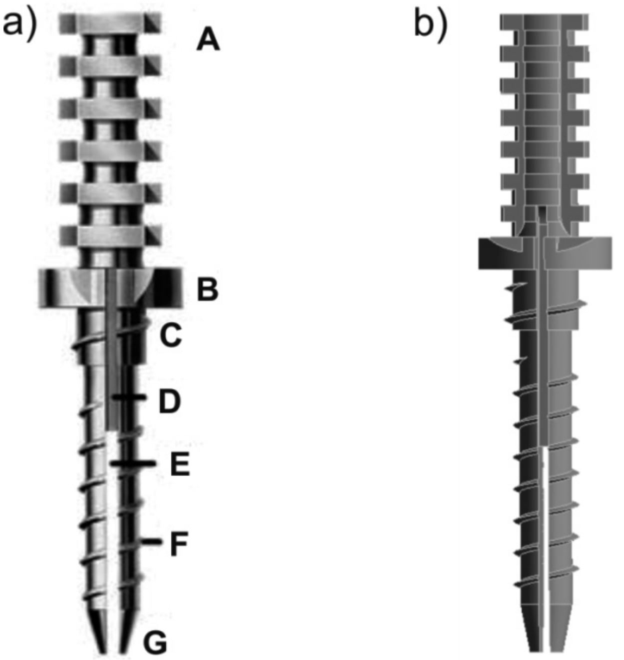

Fig. 1. Construction of the Flexi-Flange [7]: a) the actual, b) geometrical; A – highly retentive head, B – flange (third tier), C – second tier, D – entire length of shank is vented, E – patented split-shank design, F – parallel sided sharp threads, G – tapered end of the post-and-core arm

Table 1. Material data used in the calculation

	Young's modulus [GPa]	Poisson's ratio
Titanium alloy Ti-6Al-4V ELI	110	0.33
Stainless steel Cr-Ni	200	0.30
Root (Dentine)	18.60	0.31
Zirconium oxide ceramics	210	0.30
Glass ionomer cement	4	0.35
Reconstruction of the stump (Ti-Core Natural)	22.20	0.30
Gutta-percha	0.00069	0.45
Periodontium	0.0689	0.45
Cancellous bone	1.37	0.30
Cortical bone	13.70	0.30

stump τ_{xy} = 0.9 MPa (II variant). For the II variant τ_{xy} were not fund in the gutta-percha;
- the maximal τ_{yz} were also observed for the post and were equal to: τ_{yz} = 10 MPa (I variant), τ_{yz} = 40 MPa (II variant). The minimal values of τ_{yz} were present for the I variant and were equal to τ_{yz} = 2 MPa – were localized in the periodontium, the reconstruction of the stump and in the cancellous bone. For that variant τ_{yz} wasn't registered for the gutta-percha. The lowest τ_{yz} for the I variant were localized in the gutta-percha and were equal to: τ_{yz} = 0.06 MPa;
- the maximum values of τ_{xz} both for I and II variant were localized in the post and were respectively: τ_{xz} = 10 MPa and τ_{xz} = 40 MPa. The lowest values of τ_{xz} for I variant – τ_{xz} = 1 MPa were localized in the periodontium, the cancellous bone and the reconstruction of the stump. For that variant τ_{xz} were not found in the gutta-percha. The lowest values of τ_{xz} for the II variant were localized in the gutta-percha – τ_{xz} = 0.11 MPa.

Results of FEM analysis made for the post-and-core (made of Ti6Al4V ELI alloy) – tooth system shown that the maximal displacements were registered for the crown both for I and II variant and were respectively: Δl = 0.09 mm and Δl = 0.30 mm. The lowest values were equal to: Δl = 0.01 mm and were localized in the cortical bone, the cancellous bone and in the gutta-percha for the I variant and in the gutta-percha for II variant. The largest values of the equivalent strains were observed in the periodontium and were respectively: ε_{max} = 13% (I variant), ε_{max} = 30% (II variant). The lowest values of the equivalent strains were equal to ε_{max} = 0.02% and were localized in the crown and the reconstruction of the stump (I variant) and in the gutta-percha (II variant). However the largest values of equivalent stresses were observed in the post: σ_{max} = 110 MPa (I variant), σ_{max} = 250 MPa (II variant), while the lowest equivalent stresses were performed in the gutta-percha: σ_{max} = 0.06 MPa (I variant), σ_{max} = 0.20 MPa (II variant). In addition, the shear stresses were investigated in each element of the analysed system:
- the maximal values of τ_{xy} were localized in the post and were equal to: τ_{xy} = 20 MPa (I variant), τ_{xy} = 55 MPa (II variant). The minimal values of τ_{xy} were localized in the gutta-percha τ_{xy} = 0.02 MPa (I and II variant);
- the maximal values of τ_{yz} were observed in the post and were equal to: τ_{yz} = 9 MPa (I variant), τ_{yz} = 30 MPa (II variant). The minimal values of τ_{yz} = 2 MPa for the I variant were localized in the periodontium, the cement and in the cancellous bone, while the lowest values of τ_{yz} for II variant were localized in the gutta-percha and were equal to: τ_{yz} = 0.02 MPa;
- the maximum values of τ_{xz} for I variant were equal to τ_{xz} = 7 MPa and were localized in the cortical bone, while for II variant in the crown – τ_{xz} = 25 MPa. Moreover the smallest values of τ_{xz} both for I and II variant were localized in the gutta-percha and were respectively: τ_{xz} = 0.01 and τ_{xz} = 0.06 MPa.

It can be seen that for the post-and-core (made of Ti6Al4V ELI alloy) - tooth system, irrespective of the load variant smaller values of the considered parameters have been showed.

Summary

This work is a part of research carried out by the authors concerning improvements of functional properties of endodontic posts that are used in dental prosthetics [8]. The main aim of the study was to determine the influence of the applied material and load method for useable properties of the post-and-core with the use of finite element method. The stomatognathic system is very complex, that caused

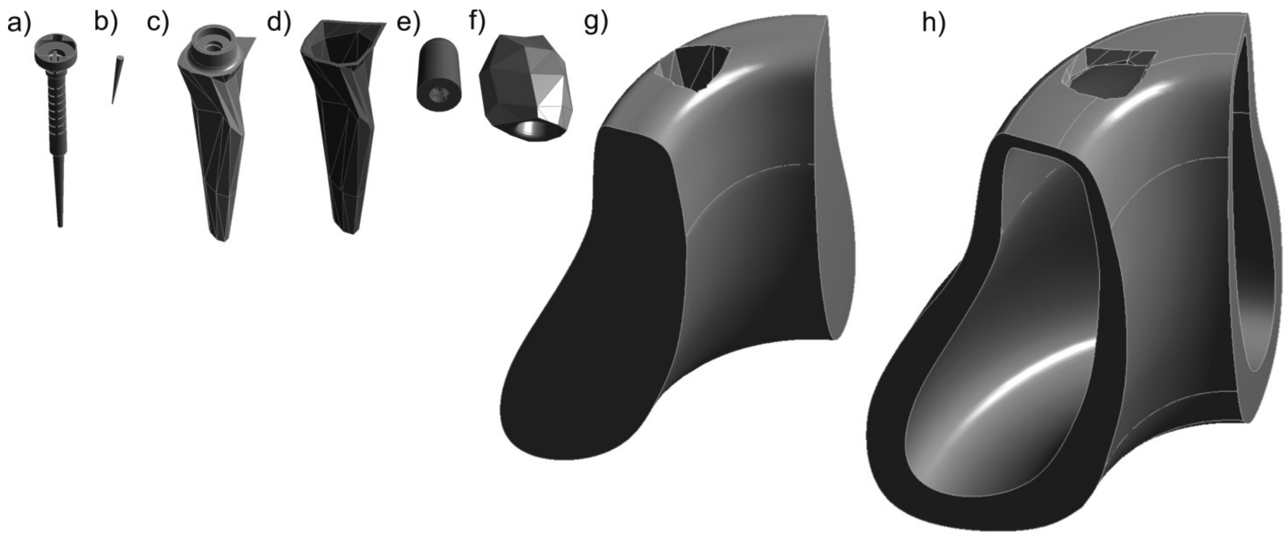

Fig. 2. Geometrical model of: a) cement, b) gutta-percha, c) root, d) periodontium, e) reconstruction of the stump, f) crown, g) cancellous bone, h) cortical bone

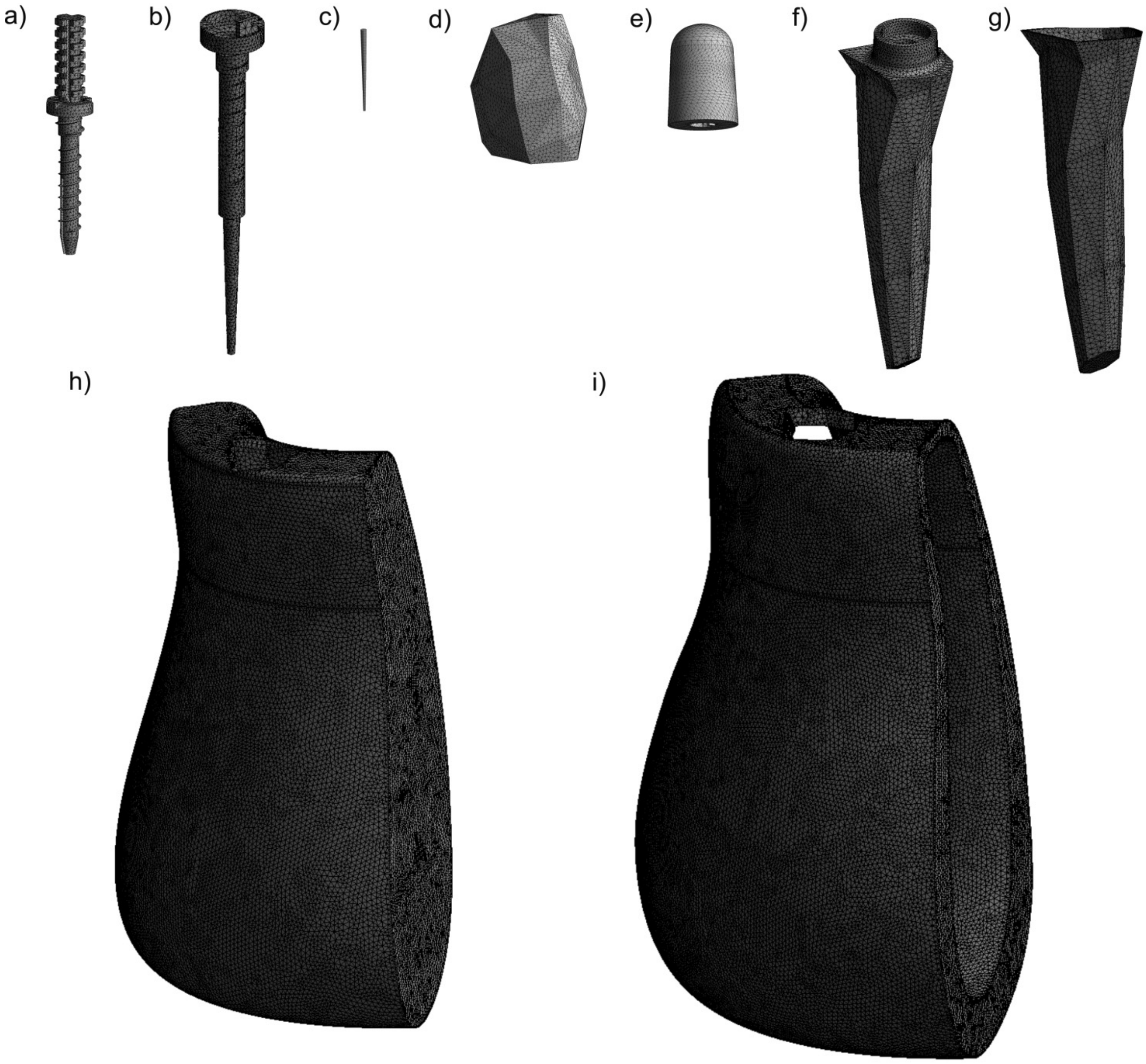

Fig. 3. Discretized elements of post-and-core – tooth system: a) dental post, b) cement, c) gutta-percha, d) root, e) periodontium, f) reconstruction of the stump, g) crown, h) cancellous bone, i) cortical bone

Table 2. The results of the numerical analysis – I variant (0^0) post made of Ti6Al4V ELI

	Elements of the post-and-core – tooth system								
	Post	Root	Periodontium	Cortical bone	Cancellous bone	Crown	Cement	Gutta-percha	Reconstruction of the stump
Total displacement, mm	0.06	0.03	0.03	0.01	0.01	0.09	0.03	0.01	0.06
Equivalent strain ε_{max}, %	0.10	0.33	13	0.14	0.42	0.02	0.22	0.04	0.02
Equivalent stress σ_{max}, MPa	110	65	9	19	6	51	9	0.06	7
Shear stress τ_{XY}, MPa	20	15	1	2	1	15	4	0.02	1
Shear stress τ_{YZ}, MPa	5	8	2	6	2	9	2	–	2
Shear stress τ_{XZ}, MPa	5	5	1	7	1	5	1	0.01	1

a lot of problems which are considered by many researchers in centres in the country as well as abroad. There are different kinds of applied cements, core's materials, values of applied force as well as locations and angles [3-6, 9-13], therefore, possibility of results comparison is limited. The Flexi-Flange post from the Essential Dental Systems, Inc. was analysed, because it provides high retention in the root. The analysis was performed for two loads variants: I variant – the force was applied to the incisal edge of the tooth axis, II – variant – the force was applied at the angle of 45° to the axis of the tooth. In addition, the analysis was performed for post-and-core made of two metallic biomaterials: Cr-Ni stainless steel and Ti6Al4V alloy. On the basis of the obtained results it was found that there is diverse distribution of displacements, strains and stresses. Regardless of applied core material, the largest values of displacements,

Table 3. The results of the numerical analysis – I variant (0^0) post made of Cr-Ni stainless steel

	Elements of the post-and-core – tooth system								
	Post	Root	Periodontium	Cortical bone	Cancellous bone	Crown	Cement	Gutta-percha	Reconstruction of the stump
Total displacement, mm	0.06	0.03	0.03	0.01	0.01	0.09	0.03	0.01	0.06
Equivalent strain ε_{max}, %	0.08	0.33	13	0.13	0.42	0.02	0.25	0.04	0.03
Equivalent stress σ_{max}, MPa	185	60	9	19	6	48	10	0.10	8
Shear stress τ_{XY}, MPa	25	14	1	2	1	12	5	0.06	2
Shear stress τ_{YZ}, MPa	10	8	2	6	2	8	4	–	2
Shear stress τ_{XZ}, MPa	10	5	1	7	1	5	2	–	1

Table 4. The results of the numerical analysis – II variant (45^0) post made of Ti6Al4V ELI

	Elements of the post-and-core – tooth system								
	Post	Root	Periodontium	Cortical bone	Cancellous bone	Crown	Cement	Gutta-percha	Reconstruction of the stump
Total displacement, mm	0.21	0.10	0.07	0.02	0.02	0.30	0.10	0.01	0.21
Equivalent strain ε_{max}, %	0.14	1.0	30	0.30	1,0	0.06	0.55	0.02	0.06
Equivalent stress σ_{max}, MPa	250	205	22	45	15	125	22	0.20	17
Shear stress τ_{XY}, MPa	55	45	3	2	1	30	11	0.02	1
Shear stress τ_{YZ}, MPa	20	25	3	10	2	30	7	0.02	2
Shear stress τ_{XZ}, MPa	20	25	3	12	2	18	4	0.06	3

Table 5. The results of the numerical analysis – II variant (45^0) post made of Cr-Ni stainless steel

	Elements of the post-and-core – tooth system								
	Post	Root	Periodontium	Cortical bone	Cancellous bone	Crown	Cement	Gutta-percha	Reconstruction of the stump
Total displacement, mm	0.20	0.10	0.07	0.02	0.02	0.30	0.10	0.01	0.21
Equivalent strain ε_{max}, %	0.23	1.0	32	0.31	1,0	0.06	0.55	0.02	0.06
Equivalent stress σ_{max}, MPa	460	200	22	45	15	125	22	0.25	17
Shear stress τ_{XY}, MPa	80	45	3	3	1	30	11	–	0,9
Shear stress τ_{YZ}, MPa	40	25	3	10	2	30	7	0.06	3
Shear stress τ_{XZ}, MPa	40	25	2	15	2	18	4	0.11	3

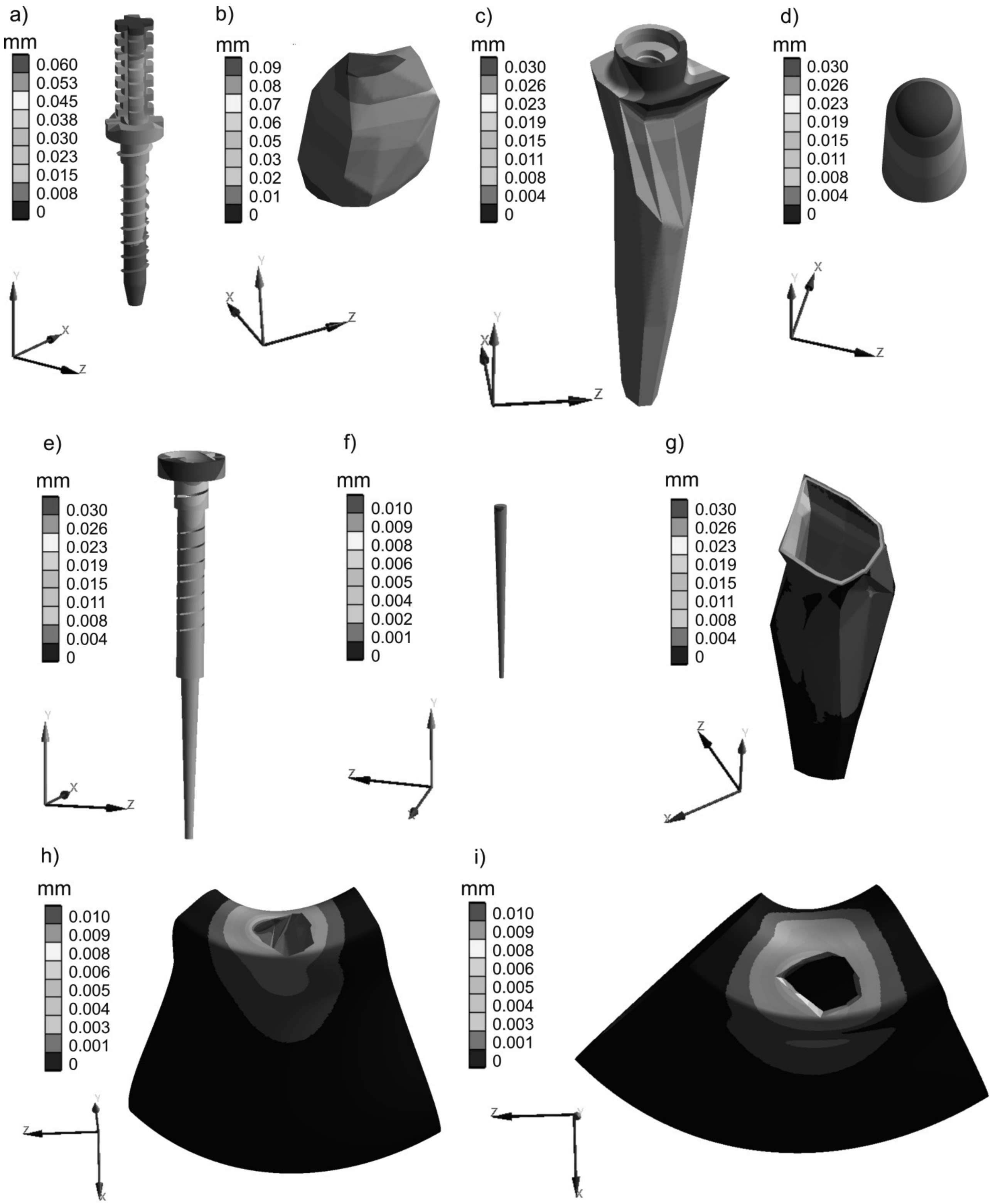

Figure 4. The sample displacements distribution in elements of the analysed system (I variant): a) post made of Cr-Ni stainless steel, b) crown, c) root, d) reconstruction of the stump, e) cement, f) gutta-percha, g) periodontium, h) cancellous bone, i) cortical bone

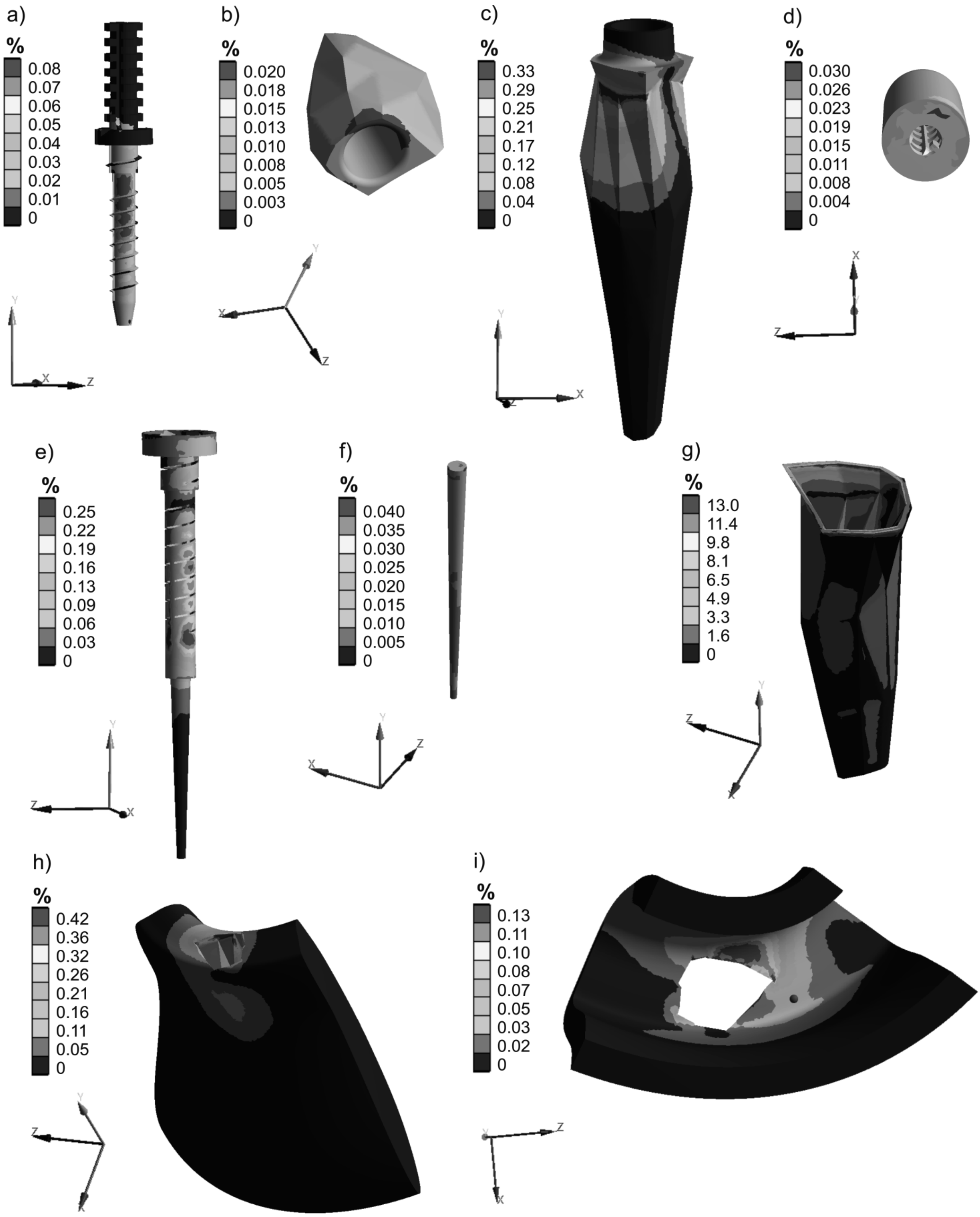

Figure 5: The sample strains distribution in elements of the analysed system (I variant): a) post made of Cr-Ni stainless steel, b) crown, c) root, d) reconstruction of the stump, e) cement, f) gutta-percha, g) periodontium, h) cancellous bone, i) cortical bone

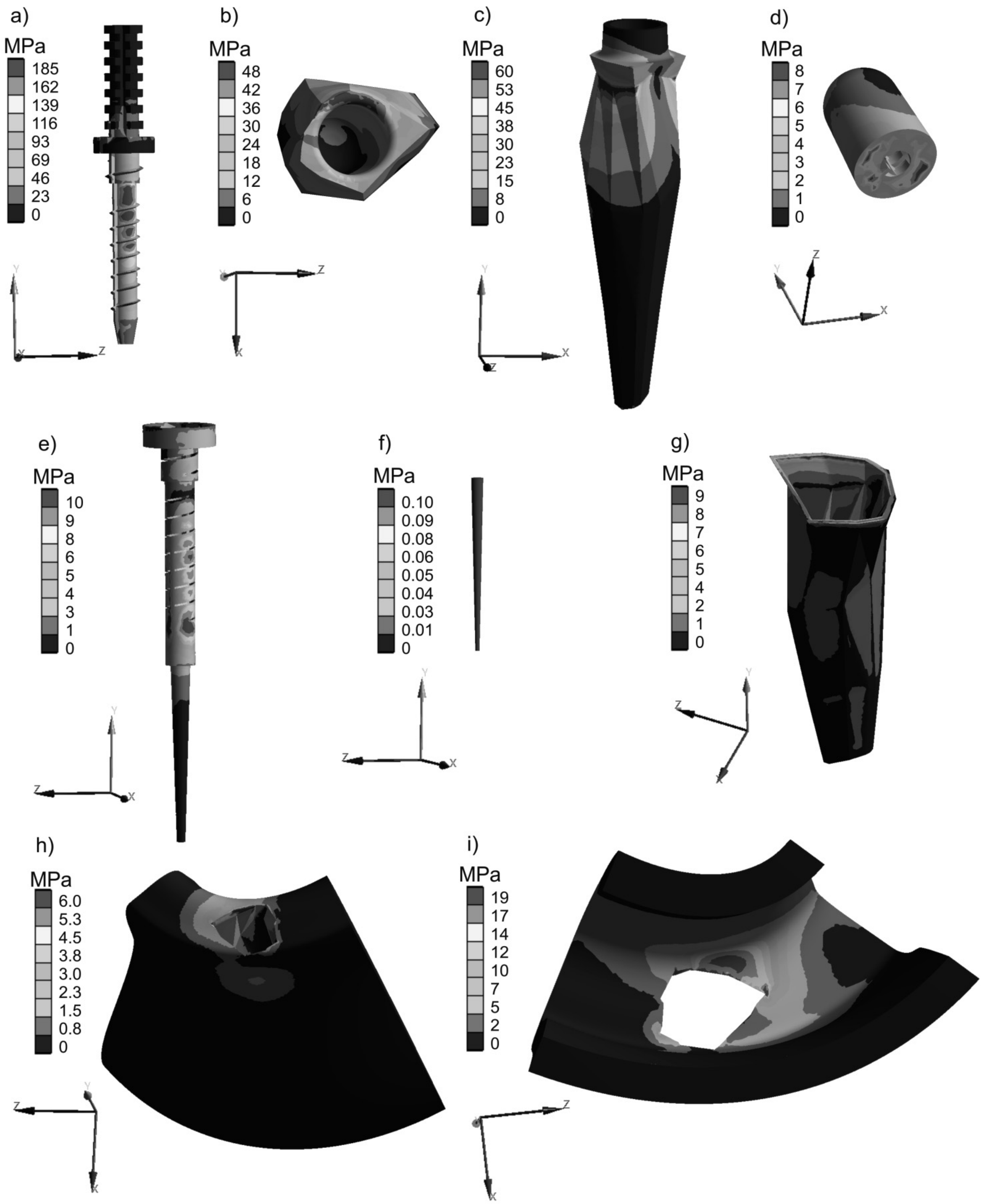

Figure 6. The sample equivalent stresses distribution in elements of the analysed system (I variant): a) post made of Cr-Ni stainless steel, b) crown, c) root, d) reconstruction of the stump, e) cement, f) gutta-percha, g) periodontium, h) cancellous bone, i) cortical bone

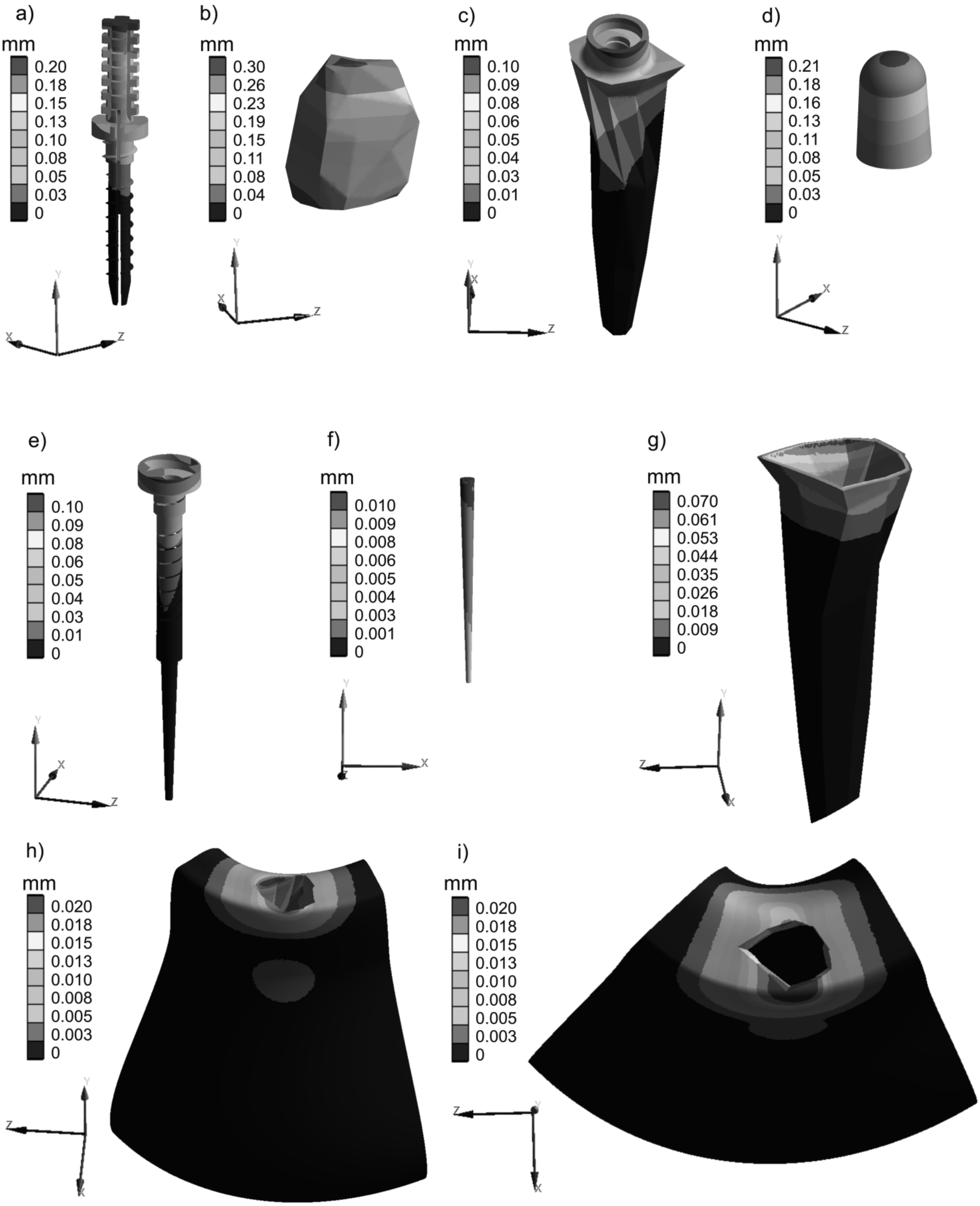

Figure 7: The sample displacements distribution in elements of the analysed system (II variant): a) post made of Cr-Ni stainless steel, b) crown, c) root, d) reconstruction of the stump, e) cement, f) gutta-percha, g) periodontium, h) cancellous bone, i) cortical bone

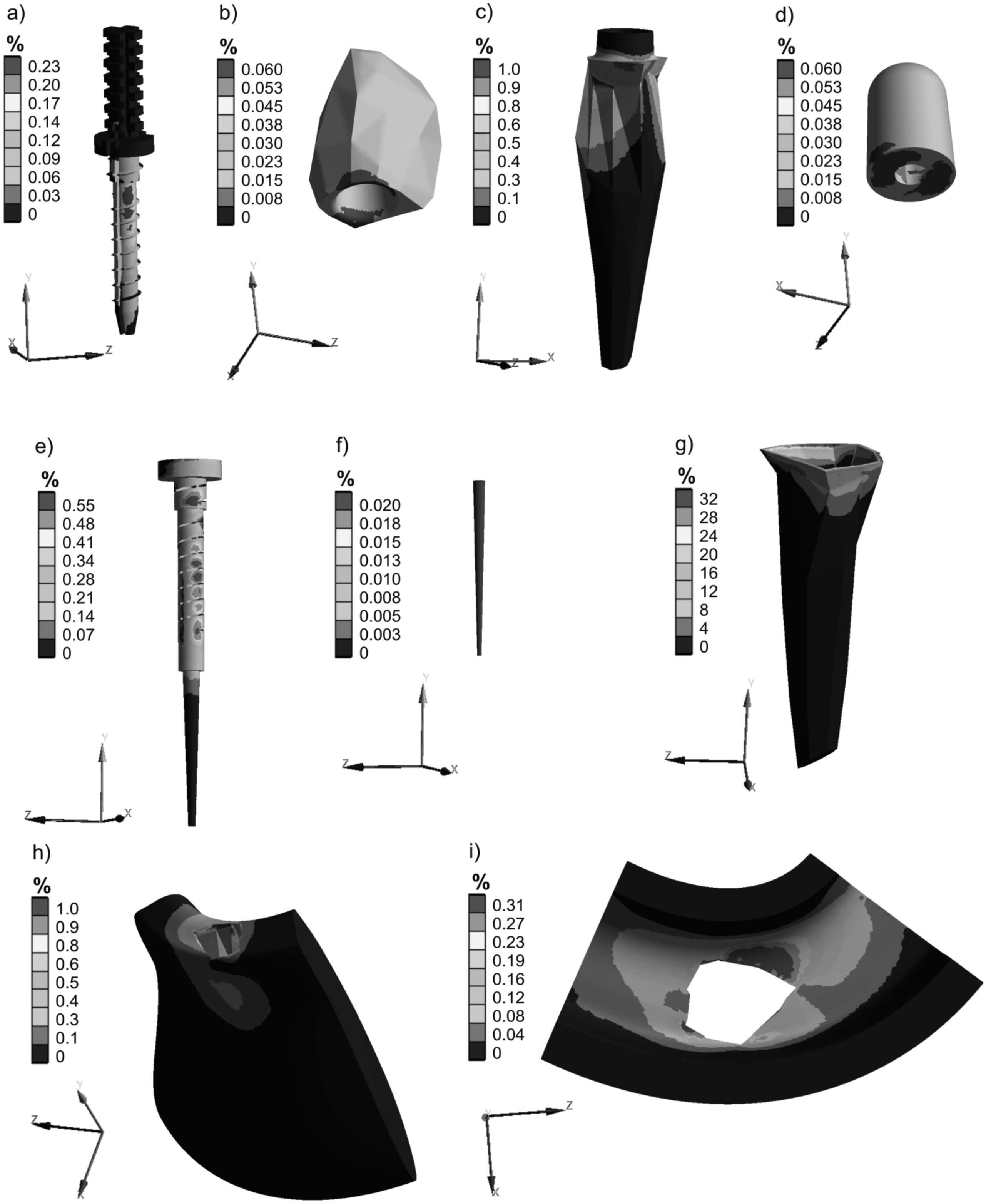

Figure 8. The sample strains distribution in elements of the analysed system (II variant): a) post made of Cr-Ni stainless steel, b) crown, c) root, d) reconstruction of the stump, e) cement, f) gutta-percha, g) periodontium, h) cancellous bone, i) cortical bone

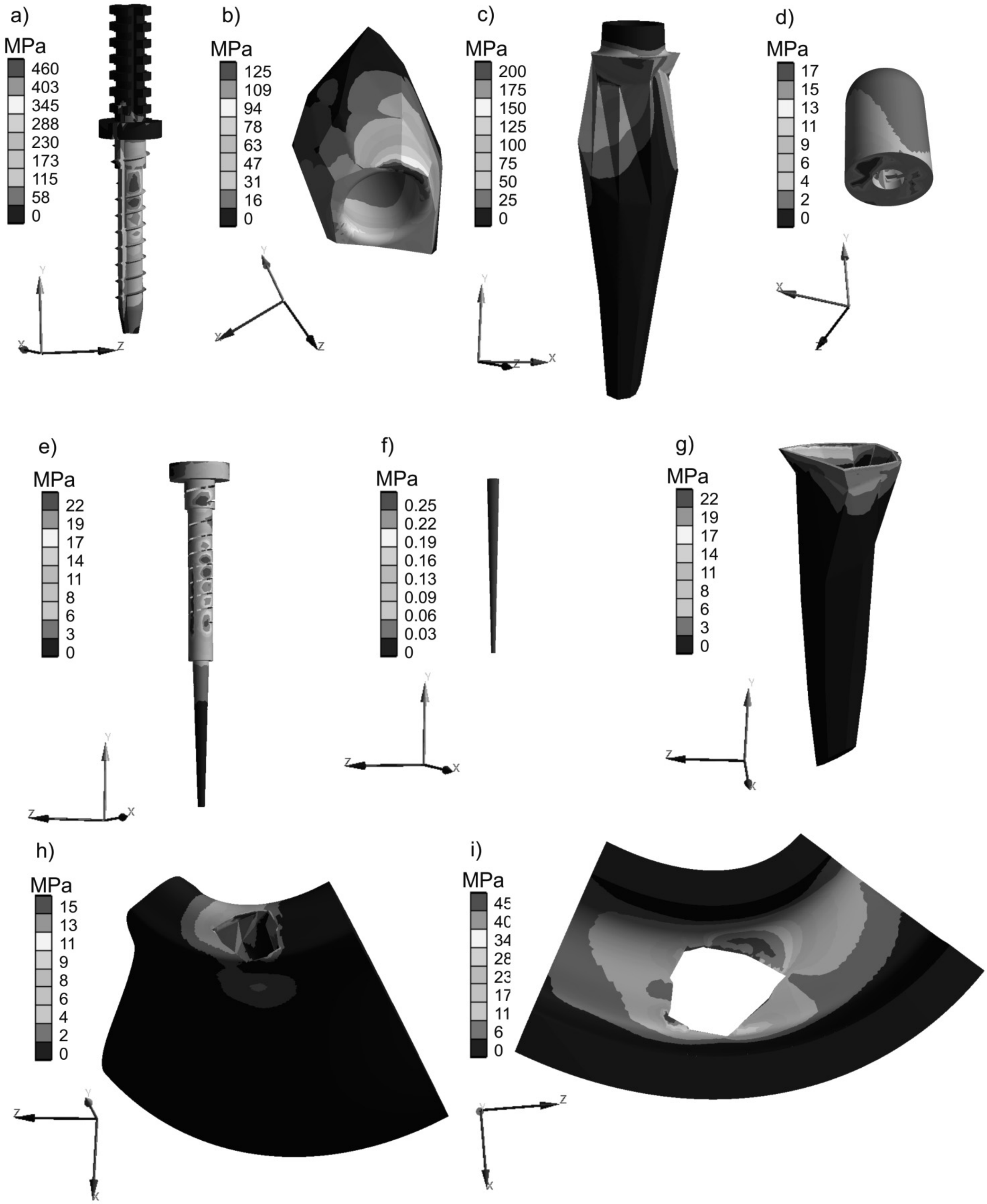

Figure 9. The sample equivalent stresses distribution in elements of the analysed system (II variant): a) post made of Cr-Ni stainless steel, b) crown, c) root, d) reconstruction of the stump, e) cement, f) gutta-percha, g) periodontium, h) cancellous bone, i) cortical bone

strains and stresses were occured when the system was loaded on the labial surface at the angle of 45° to the axis of the tooth. In addition, it was found that regardless of analysed loads variant, the obtained results of equivalent stresses of post-and-core didn't exceed the yield strength of metallic biomaterials (Ti6Al4V ELI alloy – $R_{p0,2}$ = 780 MPa, Cr-Ni stainless steel – $R_{p0,2}$ = 680 MPa), which provides strains of the post-and-core in elastic range. It was also reviled that stresses in the rest of elements of analysed system didn't exceed their compressive strength. The received results confirm the fact, that the analysed post-and-core provides high retention in the root, low pressure at the wall of the root, regardless of applied post's material as well as load. The results of the numerical analysis with the use of the finite element method are a valuable source of information to correct design of shape as well as geometrical properties of posts-and-cores, mechanical properties and the degree of strengthening metallic biomaterial. So a comprehensive study will doubtless lead to an increased interest of dentists. In the next step, experimental research will be conducted. It can be stated that the maximum values of the applied load Fmax = 300 N (that load stemmed from the literature reports regarding the acquired occlusal forces) is safe for that kind of the post irrespective of way of force application. In addition, no significant differences in the stresses for both analysed post's materials were found. Besides, the Authors in the future want to determine the values of the connection force on the post-and-core – cement boundary with the use of FEM. The obtained results will be helpful with selection of surface modification methods of the posts in order to adapt them to individual needs of patients.

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