Stress distributions in mandibles around osseo-integrated implants, according to the occlusion pattern, using MSC/NASTRAN three-dimensional modeling

ABSTRACT

Stress distribution induced by mastication loads in bones holding osseointegrated implants, has been studied by many authors. One of the main reasons for that research is that stress concentration in a specific bone region, can unchain the process of bone reabsorption (loss with contraction) and, consequently, the failure of the implant-based therapy.

The proper choice of the occlusion pattern, hereafter considered the way prosthetic and dental cusps fit together, is fundamental for the homogeneous distribution of mastication loading around implants that totally support the prosthesis.

Through the Finite Element Method, the stress distribution around the prosthesis supporting implants has been studied. Two kinds of occlusion patterns have been considered: canine guide and balanced occlusion. The three-dimensional finite element model of the lower jaw with a prosthesis supported by six osseointegrated implants was developed and analyzed regarding both loading (occlusion) conditions. MSC/XL was used for pre and post-processing and MSC/NASTRAN for the analysis.

Considering just the biomechanical aspects, it was observed that:

- The balanced occlusion shows stress distributions around the implants more homogeneous than the canine guide;
- The regions around distal (border**)** implants on both sides of the mandible were the most stressed;
- The working side shows higher stress concentration in both simulations.

Many interesting challenges were identified allowing to expect for increasing interest in this interdisciplinary field of research.

Authors:

Wolodymir Boruszewski

Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil

Pedro Tortamano Neto

Universidade de São Paulo, São Paulo, SP, Brasil

Tetsuo Saito

Universidade de São Paulo, São Paulo, SP, Brasil

1. INTRODUCTION

Osseointegrated implant, as a therapeutic resource in odontology, has been used for two decades. In this short period, the dental surgeons witnessed, without any doubt, the fastest evolution of the reconstructive therapy ever seen in odontology. However, as a consequence, some knowledge has been lost regarding the real behaviour of the phenomena during osseointegration.

Among the missing points, the one concerning its biomechanical behaviour is perhaps one of the greatest. There are doubts about the distribution of the mastication loads in bones with implants, originating numerous interrogations. Among them one should mention: What loading level each implant can withstand? Which one is the best configuration for the prosthesis supported by implants?

Once that there is no device such as the periodontal ligament of the natural teeth, to reduce the impact of the occlusal loads transmitted to the bone, one is allowed to conclude that it is necessary some occlusal pattern adequate to the prosthesis supported by implants.

Other biomechanical factors interfere directly in the stresses transmitted to the bone through the prosthesis supported by implants: quality of the bone, muscular power, size and shape of the implant, type of the antagonistic arc and nocive mastication habits. However, the factors previously described vary tremendously, from individual to individual, being quite a challenging field of studies in clinical research.

According to our understanding, the choice of the proper occlusal pattern is extremely important to the success and longevity of the prosthesis supported by implants, for, once reached the osseointegration, the main cause of bone loss around the implants is the overloading of the attachments associated to the bacterial plate.

According to PARKER[35] (1993), many authors are so much concerned with the design of the implant - and its intermediate parts - and with the study of the interface bone-implant, that they seem to forget the importance of the occlusion to the success of the prosthesis supported by implants.

Many authors suggest occlusion patterns to prosthesis supported by implants, in order to get better stress distribution in the bone with implants. However, there is no work showing the variation of the stress distribution in the surrounding bone, as a function of the occlusal pattern.

In our previous works, the stress distribution transmitted to the bone containing a single osseointegrated implant was studied varying both the type of bone and the direction of the applied load. However, the results should not be considered when the implant is connected to another one through a frame, as a part of a prosthesis supported by implants.

According to BRANEMARK[5] (1983), natural teeth present nerves in the periodontal membrane, that protect them against excessive occlusal forces. Although many other factors are present in the action of the neuromuscular reflex arc, the osseointegrated implants do not present any specific protection against that type of trauma. Therefore, restorations with deficient occlusion, in osseointegrated implants, can present a quite higher failure potential.

As shown hereafter, some authors suggest that the complete prosthesis supported by implants should be made with an occlusion pattern the as close as possible to the natural teeth, while other defend occlusion patterns equal to those applied to total prosthesis. Such a variety of opinions leads us to believe that there is not enough evidence for conclusive statements.

According to our judgment, it is not valid to propose some type of ideal occlusion to the prosthesis supported by implants, in order to get a uniform distribution of the occlusal loads between all implants that support them, without knowing how the implants absorb the stresses generated by mastication loads.

HOBO et al[13] (1989) report that there are few works studying the relationship between the types of occlusion and the occlusal loads generated in prosthesis supported by implants. Thus, it is not known, so far, the effect of various types of occlusal schemes in prosthesis supported by implants.

2. LITERATURE REVIEW

In order to soften the literature review, this chapter was split in two parts:

- Occlusal patterns proposed in literature
- Study of the stresses transmitted to the bone containing osseointegrated implants.

2.1 Occlusal patterns proposed in literature

Examining the related bibliography, it was observed that the authors try to name and describe occlusal patterns that transmit the stresses generated during mastication cycle to the periodontal tissues, without causing any damage to the stomatognatic (mastication) system.

According to MOHL[30] (1989), BONWIL[3] (1885) stated the "Geometric laws and articulation mechanics", analyzing and describing the mandible in terms of an equilateral triangle with 10 cm sides, that connect both condyles and the mesio-incisal angles of the lower central incisors. His concept of an ideal geometry was "with the purpose of putting in contact the most of the grinding surface of the premolars and molars and, at the same time, having all incisors in action during lateral movements" for complete prosthesis. The resulting balanced occlusion would allow the "equalization of the muscles' action of both sides simultaneously, obtaining so, not only the most of the grinding surface in each movement" but also "the equalization of pressure and force in both sides or parts of the dental arcs ". Those conditions, presumably, would help to reduce the deviation and the displacement of the total prosthesis active in the mouth.

The concept of balanced occlusion, is often credited to FERDINAND GRAF SPEE [42] who, in 1890, presented his observations about the function of human natural teeth. According to his writings, the lower teeth occlusal contact surfaces slide against those of the upper teeth; those contact areas are in the same cylindrical surface and the cylinder horizontal axis of curvature passes through the centre of the orbit medial surface, behind the lachrymal duct. The occlusion works as a grinding mill and the mandible movement occurs in "circular paths, as a pendulum and around an axis". The term Spee Curve derives from his observation that, when seen laterally, "the molars' mastication surfaces are aligned in a downward convex curve, along the mandible". He also believed that a continuation of that curve would pass along the condyle anterior surface, that "also moves in circular path with the same radius in the molars' occlusal surfaces", i.e., "in the same cylindrical surface". He concluded that, as forward and backward mandible movements happen, in a circular path, those displacements can occur at larger distances, without any need of arcs' separation, assuring then the mastication efficiency. A separation of the occlusal surfaces is unavoidable only to overcome the contact of the strongly protruded upper and lower teeth. However, that also can be eliminated by abrasion. That should be considered in the construction of the prosthesis, not only to allow the best mastication, but also to avoid the cantilever effects during mastication.

For some time, the concept of balanced occlusion was also applied to the natural teeth. Patients without those principles had their occlusion considered "pathologic". In many cases, aiming to get balanced occlusion in toothed patients, occlusal wastages were done through abrasive pastes to get simultaneous contacts of all teeth in their excursions.

NAGAO[34] (1919) and SHAW[40] (1924) were the first to disagree about the application of balanced occlusion to the natural teeth, stressing the importance of the canine as a guide of the excursive movements. However, his works were not accepted at the beginning.

McCOLLUM[25] (1938) introduces the concept of terminal axis of simple support, defending balanced occlusion for natural teeth and in toothless people rehabilitation.

In the 20's, various researchers, as STILLMAN; McCALL[44] (1927), cogitated that excessive forces transmitted to teeth would be the cause of bone reabsorptions in bearers of total prosthesis and periodontal lesions in natural teeth.

SCHUYLER[38] (1929) was the first to believe that the concepts of balanced occlusion should be applied to the natural teeth. In 1935, the author[39] proposes the use of balanced occlusion and an even distribution of the occlusal loads between all teeth of the arcs, through contact between the functional cusps.

Only in 1955, McCOLLUM; STUART[26], and later STUART; STALLAR[46] (1957) developed clinical works in which the occlusion was protected by the canine. The authors noticed that, when balanced occlusion was used, the works failed due to the trauma caused by simultaneous contacts, periodontal problems or dysfunction of the temporal-mandibular articulation.

D`AMICO[6] (1958), through his study about skulls of primitive men and Californian Indians, also disputed the philosophy of his days, about the prescription of the bilateral balanced articulation to the rehabilitation of toothed patients, stressing the importance of the canines.

Among his conclusions it should be mentioned:

- the morphology of human natural teeth is designed for mastication of carnivorous diets;
- the canines are constants in number, position and alignment on dental arc;
- the canines are useful to guide the mandible during eccentric movements, when antagonistic teeth are in functional contact;
- the position of condyles in the fosses is produced by dental contacts, and not by the guides;
- the upper canines, when in functional contact with the lower canines and pre-molars, determine the side and protrusion (forward) mandible movements;

- the canines are extremely sensitive and, when their antagonistic teeth are in contact during eccentric mandible movements, transmit more than any other tooth the impulses of the periodontal properceptors to the mastication muscles, reduce the muscular stress and perhaps also the magnitude of the applied force, playing then a protective function.

JERGEL[16] (1963) found the highest concentration of nerves in the canine, when compared with the other teeth. That observation strengthened the concept of occlusion protected by the canine.

KAWAMURA[17] (1967) demonstrated that teeth, in decreasing order of sensitiveness to pressure are, the incisors, canines, premolars and molars.

STALLARD; STUART[43] (1963) accepted the fall of the theory of balanced occlusion to the natural teeth, admitting the failure of many clinical cases worked out in toothed patients, according to the concepts of that type of occlusion. Performing a study where they analyzed the principles underlying occlusal restorations in natural teeth, they observed that in balanced restorations the canines were, sometimes, left out of the occlusion and sometimes left so low that make them unable of interfering in the lateral and protrusive movements. In some occasions, a restoration was placed in the lingual surface of the superior canine in order to put it in contact with the inferior one. All that was done as if the canine had no function. However, probably the canines have still the same potential that they had primitively. One of their functions would be to prevent traumas to the vestibular cusps and to avoid the incisors waste during lateral movements. The canines should be carefully restored in order to protect the anterior teeth; these, when closed in protrusive position (peak-to-peak), protect the edges of posterior teeth's cusps.

STUART[45] (1960) observed the occlusion of 60-year and older patients with no contact and noticed that their molars did not touch during eccentric movements; by the other side, in maximum contact between cusps, anterior teeth presented a labial contact.

The works of STALLARD; STUART[46] (1957), D`AMICO[6] (1958) and of STUART[45] (1960) called special attention to anterior teeth, as protective of the posterior ones during excursive movements and while these protect the anterior ones during centric positions. This principle, today denominated "Mutual Protection", is stated by MOHL[30] (1989), as follows:

- in the position of maximum contact between cusps, the primary occlusal load, directed axially, is absorbed by contact areas only in posterior teeth. Anterior teeth just touch and should not support the strong potentially forces in the centric position.

- in protrusion, the horizontal and vertical trespass ratios of the incisors produce an incisor guide steep enough to interrupt the occlusion of posterior teeth.

- in lateral excursion, the trespass vertical and horizontal ratios of contacting teeth, in the working side, should be steep enough to cause disocclusion of all teeth of the balancing side. The question about whether only the canine should be in contact with the working side (canine guide), whether the premolars should also be in contact, or all posterior teeth at the working side should be in contact (group function), is determined based upon each specific case, depending upon clinical factors as previous relationships, root-crown proportions and the degree of mobility or trembling of participant teeth.

According to HOBO[13] (1989), the canine should be the only guide of the lateral movement, once it presents a satisfactory proportion root-crown, a good and dense alveolar bone around it and being far from the articulation; factors that reduce the stresses acting on it. In addition, the canine presents a great number of properceptors along its periodontal membrane, the one that controls the load during lateral movements.

SCHUYLER[38] (1929) introduced the concept of "Group function", believing that in some cases the canine was not in good condition to withstand alone the lateral loads during lateral movements. In this type of occlusion, along with the canine, the **external slopes** of the vestibular cusps of the lower posterior teeth, at the working side, guide the lateral movement, sliding against the internal slopes of the vestibular cusps of antagonistic teeth, simultaneously, while teeth of the balancing side have no contact.

WILLIAMSON; LUNDQUIST[50] (1983) affirm that only when a posterior disocclusion is obtained through an adequate anterior guide, the high activity of the temporal and masseter muscles is reduced. However, it is not the contact between the canines that reduces the activity of the lifting muscles, but the elimination of the posterior occlusal contacts.

HARALDSON[10, 9] (1977) (1985) compared the mastication force in patients with natural teeth and patients using prosthesis supported by implants, concluding that there are no significant differences between the cases. He believes that the mastication force in patients using prosthesis supported by implants is controlled by the neuromuscular mechanism, through the mastication muscles.

According to LEKHOLM[20] (1983), a bad occlusion is responsible for loads and stresses distributed heterogeneously, leading to bone loss and mobility of the implants. For a better load distribution, he proposes the use of balanced occlusion to prosthesis completely supported by implants, for thence, the lateral forces generated during excursive movements would be equally distributed between all teeth.

However, according to HOBO[13] (1989), balanced occlusion is not indicated to the prosthesis completely supported by implants, for, during excursive movements, posterior teeth of working and balancing sides, that contact, generate many lateral loads. Those loads are prejudicial to the components of the prosthesis supported by implants, mainly to the interface bone-implant. In order to defend his point of view, he still adds that the loads generated by the contact of posterior teeth in centric position are well supported by the implants, once that those are transmitted vertically and simultaneously to the implants.

JEMT[15] (1986) agrees with HOBO[11] (1989), concerning the occlusal pattern used in the prosthesis completely supported by implants. He justifies his position by saying that the implants that support those prostheses are overloaded by the lateral loads generated by the contacts of posterior teeth, during eccentric movements, once that they act in the anterior portion of the mandible. In other words: there exists a cantilever (a free extremity) potentializing the lateral loads generated in the posterior region.

MIRALLES; MANNS[29] (1989), through comparative electromiographic (muscular activity visualization) study of the lifting muscles of the mandible (timeral and masseter), between balanced occlusion and canine guide in total prosthesis, noticed a minor muscular action of that last one, during lateral movements. That action can be a factor to prevent nocive mastication habits.

LÓPEZ[21] (1993) prescribes the Mutual Protection with canine guide and Centric Relation coincident with the position of maximum contact between cusps to the prosthesis totally supported by implants. That position is explained by the fact that the canine guide is the easiest to be adjusted, for one simply eliminates in laterality all contacts that should not be in the region anterior. In the case of balanced occlusion, it can be quite difficult to distinguish the contacts considered physiological of those which are true interferences.

HOBO et al[13] (1989) add that there is not enough research justifying a concept of occlusion appropriate to the prosthesis supported by implants, but suggest the following criteria to different clinical situations, in order to reduce the horizontal loads over the implants:

- for prostheses completely supported by implants, one should search the Mutual Protection to get the posterior disocclusion;

- balanced occlusion should be used in overdentures;

- in prosthesis supported by implants in the anterior region around the canines, the group function (an occlusal pattern between balanced occlusion and canine guide) is recommended. Therefore, during horizontal movements, the lateral loads will be divided between the prosthesis and natural teeth;

- in posterior prosthesis supported by implants, with anterior teeth present, the Mutual Protection with posterior disocclusion is indicated.

PARKER[35] (1993), after a thorough literature review about the importance of the occlusion in odontology, concluded that the majority of the authors adopt the same criteria of optimum occlusion applied to natural teeth, to the prosthesis supported by implants. He still emphasizes the importance of eliminating the nocive mastication habits and enabling an optimum occlusion to the prosthesis supported by implants with respect to the natural teeth.

2.2 Study of the stress distribution transmitted to the bone around osseointegrated implants

Many authors[5] believe that excessive stress concentration in the bone with implants causes necroses and, as a consequence, reabsorption of that bone. By the other side, low stress levels can produce osseous atrophy, similar to the loss of the alveolar crest, when one removes natural teeth (HASSELER et al[12] (1977), RIEGER et al[37] (1990), MEIJER et al[27] (1993)).

WOLFF et al[51] (1990) proposed the concept of osseous remodeling induced by stress. However, the magnitude as well as the direction of the stress, responsible by osseous reabsorption or apposition, presently configure a point of controversy between the researchers. Actually, it is accepted the existence of a critical stress value that unchains higher reabsorption.

Presently, it is admitted an ideal value of stress, for which reabsorption equals apposition. Values above or below those levels lead to the osseous atrophy. There is, as is obvious, a maximum load, once that high stress values cause large osseous destruction, considered pathologic reabsorption.

HASSLER[12] (1977) studied the osseous remodeling in rabbits. His work consisted in implanting scaleable load cells over their craniums. Those animals, when submitted to 250 psi in compression, presented more osseous apposition, while those submitted to stresses higher than 400 psi presented higher reabsorption.

Aiming to detect possible regions subject to osseous reabsorption due to absence or excess of stress, many authors started to study the stress distribution transmitted to the bone, generated by the mastication loads applied to the osseointegrated implants.

HARALDSON[8] (1980), using photoelasticity in load analysis around osseointegrated implants, with cylindrical thread, concluded that they present a load distribution around the implanted piece more favorable to the osseous integrity. He emphasizes that the threaded osseointegrated implant, presents lower shearing stresses in the interface bone-implant, if the artificial element is submitted to vertical loads. That opinion is corroborated by SKALAK[41] (1988) and HOBO et al (1989) [13].

SKALAK[41] (1988) still considers that such a configuration transmits the axial loads to the alveolar bone always as compression, by means of thread characteristic inclined planes. The author affirms that cylindrical pieces, but with rugged surface, present the same properties of the threaded implants, for avoiding shearing stresses.

ADELL et al[1, 2] (1981) (1986) documented that the primary or secondary occlusal trauma causes loss of the osseous tissue around the osseointegrated implant.

BORCHERS; REISCART[4] (1983) used the finite elements method to analyze the stresses generated by a ceramic implant. Higher stresses were observed in the region of the alveolar crest, mainly when the implant was submitted to transverse loads. They observed also that the presence of hard lamina or conjunctive tissue around the implant helps to reduce those stresses.

MEROUEH et al[28] (1987) analyzed the stresses generated in the alveolar bone by a fixed prosthesis, having as is support according to inferior premolar and an IMZ osseointegrated implant. The analysis was done by means of a bi-dimensional model, using the finite elements method. The authors described the prevalence of compression stresses around the natural tooth and tension stresses around the implant.

McGLUMPHY et al[24] (1988) studied, by means of photoelasticity, the stresses generated by a cantilever applied load on an IMZ osseointegrated cylindrical implant with "shock absorber". The goal of the study was to evaluate the real efficacy of the resilient internal element that those implants present. According to the authors, there was no statistical difference in stresses generated around the implants, with or without the presence of the resilient element.

TAKUMO et al[47] (1988) noticed the stresses generated around implants of alumina (Kyocera Co.), Hydroxyl-apatite (Kuraray Co.) and titanium plasma spray (Strauman Institute, Type F) by means of the finite elements method. The results were analyzed according to the Criterion of the Stresses of von Mises. For each type of implant two models were built: a first one in which the interface bone-implant was in perfect contact, and another, with interposed conjunctive tissue between both. The results indicated that the stresses generated in the crest region of the implant in alumina, with conjunctive tissue, were significantly lower than those observed in the same model without that tissue. The implants of titanium and of hydroxyl-apatite, with the presence of conjunctive tissue, presented stresses more homogenous without high stress concentration in the crest region.

KITOH et al[18] (1988) analyzed the distribution of vertical loads applied on an implant of hydroxyl-apatite, and concluded that such type of implant also presents a direct contact with the alveolar bone, as the osseointegrated implants. Contrarily to other researchers, they used the bi-dimensional finite elements method, with a section in the vestibule-lingual direction. They observed, again, the highest load concentration in the region of cortical bone around the implant's neck. because of the cross-section, and verified that not only that portion of the cortical bone was highly loaded, but also the whole cortical bone shell presented a large concentration of forces. The observed stresses in the cortical bone, around the implant's neck, were 29 times higher than those observed in the spongy bone. The authors added that in the upper region of the cortical bone compression stresses were observed, while in the lower part tension stresses were detected.

MAILATH et al[22] (1989) examined, by means of the finite elements method, in implants submitted to physiological loads, the places of stress concentration and the factors that influenced the occurrence of those concentrations. They studied the stresses generated in the bone around the implants, both qualitative and quantitatively, according to the variations of size and material of the implanted piece. They emphasized that the cylindrical implants should be preferred to the conical ones, for the implants of larger diameter generate a more homogeneous stress distribution. Because of that, the Young's Modulus of the piece should be lower than 110 000 N/mm^2.

FRENCH et al[7] (1989) analyzed the transmission of the loads to the bone in four brands of osseointegrated implants: cylindrical Core-Vent, Integral-cylindrical, IMZ-Cylindrical with shock absorber and threaded Screw-Vent. They used the photoelasticity, applying axial and oblique forces, and concluded that the systems Core-Vent and Screw-Vent unchained minor stresses in the bone. By the other side, the systems IMZ and Integral presented a better stress distribution along the surface of the piece. However, none of the four systems showed superior with respect to the stress distribution around the interface bone-implant. By its turn, the shock absorber in the system IMZ became fractured after the application of successive oblique loads, lower than 20kg.

RIEGER et al[37] (1990), based in the works of HASSLER et al[12] (1977), proposed an ideal load of 250 psi to be transmitted to the bone with implants. Regions with values below 200 psi would be subject to atrophy and above 400 psi to pathologic reabsorption.

RIEGER[37] (1990), based in literature data, studied by means of the finite elements method, in six brands of implants, Branemark, Core-Vent, Denar, Miler, Stryker and a new type of his authorship, the transmission of stresses to the bone around the implants. The results showed possible areas of atrophy and osseous reabsorption, possibly caused by hypo or hyperstress concentration in most of the pieces analyzed. The author commented one of the advantages of the use of implants over the conventional total prosthesis. Those last ones do not cause stress enough to the bone to prevent atrophy in the alveolar region. In that work it is observed that the author considered the whole bone around the implant with uniform properties for cortical bone. Therefore, the amplitude of the observed stresses shows lower when compared with other works.

VALENTIN et al[35] (1990), using the finite elements method, developed the model of a part of the mandible, containing a prosthesis supported mesially by a second premolar and, distally, by an osseointegrated implant. With the purpose of comparison, they developed two models: the first, with a cylindrical and massive implant and the other, with an empty cylindrical one. In this last one, according to the case, when bone was formed in the holed part of the cylinder, both models had the same loading distributed uniformly in the elements that corresponded to the cusps of the prostheses crowns. The results showed that the osseous portion that filled the interior of the cylinder did not present stresses upper than those observed in the rest of the alveolar bone. In both cases, the osseous distal crest region presented higher stresses.

MATSUSHITA et al[23] (1990), by means of the bi-dimensional finite elements method in a section vestibule-lingual of the mandible, noticed the variation of the stress distribution of a cylindrical implant of hydroxyl-apatite, according to the variation of the prosthesis' diameter. The authors concluded that the stress in the cortical bone was higher than in the spongy bone, mainly in the region of the implant's neck. In the presence of lateral loads, the stresses were twice as higher, and the stresses in the cortical bone decreased inversely to those in the implant.

TORTAMANO[48] (1992) studied the stress distribution transmitted to the mandible by an osseointegrated implant, varying the thickness of the cortical bone and the direction of the applied load by means of the finite elements method. A tri-dimensional finite elements method was used, analyzing an osseous block containing in its center a ten-millimeter Branemark osseointegrated implant, for two different configurations: the first with higher thickness of cortical bone, considering the implant simply supported below the cortical bone, and the second, where the external layer of cortical bone was thinner, in order to avoid the implant to contact its lower portion. It was observed that:

- the occlusal loads transmitted by the implant to the bone around it, occur non uniformly along the surface of the piece;

- in all analyzed situations, the cortical bone around the implants' neck presented higher stress concentration;

- the implant simply supported apically in the cortical bone, reduces the peak of observed stresses in the bone around the neck;

- the stresses in the mesial and distal sides of the implant's neck are higher than those in the vestibular and lingual sides of the same region;

- under oblique loads it occurs an increase of peak values of stress, being the implant simply supported or not on the cortical bone;

- an increase of stress is observed in the bone inside the thread step. That proves that the action of the thread reduces the shearing stresses in the interface bone-implant, when the piece undergoes axial loads.

MEIJER et al[27] (1993) studied by the finite elements method of a tri-dimensional model of the mandible, the stress distribution transmitted to the bone by two osseointegrated implants fixed in its anterior portion. The implants were loaded by means of vertical, horizontal and oblique loads, and studied separately or connected by a metallic bar. The higher observed stresses always occurred in the bone around the implant's neck. Oblique loads induced higher stresses, while vertical loads resulted in better distributed stresses. The union of the implants by the metallic bar did not show significant changes regarding the observed stresses. For that reason, the stress peaks that appear in the bone should be minimized through the best direction of the loads applied to the implants, instead of trying to connect the attachments or looking for new configurations for the supra-structure of the prostheses. According to the authors, the stress observed in the bone around the implants was not due only to the local deformation of the bone caused by the movement of the implants, but also to the deflection of the mandible due to the muscular force. That work seems to be the first one to study the stress distribution in the bone, considering more than one implant**.**

KREGZDE[19] (1993), through a tri-dimensional model of a skull containing a prosthesis supported by implants of the left premolars and molars, analyzed the best distribution of implants in order to get a favorable stress distribution in the bone around them. Ten different clinical solutions were analyzed to find out which one would have the best prognostic, producing the best stress distribution in the bone with implants. The analyzed options took into account the variations in the strength of the mandible bone, the type of food masticated, the number of implants supporting the prosthesis and the shape of union with the remaining natural teeth.

The best results were obtained with four implants, supporting the prosthesis, and this one divided in three parts, having just the two mesial implants connected.

KREGZDE[19] (1993) suggested that programs of finite elements should be used in dentist clinics to help in the planning of prosthesis supported by implants in order to increase the longevity in the treatments.

HARALDSON; CARLSSON[10] (1977) analyzed the mastication efficiency in 19 patients who had at least one of the their maxillaries rehabilitated with prosthesis supported by implants. The patients reported satisfaction with the mastication efficiency acquired after the rehabilitation. Three measurements of the forces of bite were done in each patient: light bite (15.7N), during mastication (50.1N) and maximum force (144.4N). It is important to emphasize that antagonistic teeth to the prosthesis supported by implants were always natural, fixed prosthesis or prosthesis supported by implants.

RANGET et al[36] (1989) analyzed the biomechanical behaviour of the prosthesis completely supported by implants, comparing them to a seesaw. The implants in anterior position in the arc would be subject to tension stresses, according to the proportion between the arm of resistance - distance between the implants - and the arm of power - length of the free extremity. The posterior implants would be subject to compression forces, resulting from the summation of the occlusal loads with the balancing of tension forces. Those would be more prejudicial to the supra-implant structures, because of the tendency to separate them from the implants, while those related to compression, even being in the upper region, tend to keep them joined. The authors still added that the free arm of the prosthesis completely supported by implants should not be longer the 20 mm in the mandible and in the maxilla. Due to the lower quality of the bone, that length should not be superior the 10 mm.

3. PROPOSITION

In the literature review, it was possible to verify the preoccupation of the authors with the transmission of the occlusal loads along the bone around osseointegrated implants, having in mind that those present a biomechanical behaviour completely different of natural teeth.

The possible regions of excessive stress are being researched, according to the variation of the type, form, material and size of the implants, intending to diagnose the zones of stress with potential to osseous reabsorption.

The Finite Elements Method has been used, with high efficiency, by some researchers, reason by which it is used here to determine an occlusal pattern for the prosthesis completely supported by implants in which occlusal loads should be distributed more homogeneously among the supporting implants.

4. MATERIAL AND METHODS

4.1 Finite elements method

Practically all natural phenomena, should be biological, geological or mechanical, can be described with help of the laws of Physics that relate, through algebraic, differential or integral equations, the variables of interest. Although the theoretical formulation of those equations is not an extremely complex task, the determination of their exact solution, in practical problems, is a wonderful challenge.

One alternative increasingly viable, given the advances in the field of computation, is to use numerical methods that, applied to the problem under analysis, and using the same equations, produce results very close of the exact ones and highly reliable.

Among those methods, one should mention the Finite Elements Method, that, for a given real structure, can be synthesized in the following steps:

- Geometric modeling: one creates a mathematical (geometric) model of the object or system in study. Typically, that is done in a computer program able of producing a solid model of the mechanical structure in consideration;

- Modeling by Finite Elements: one subdivides the geometric model in discrete elements. The resulting set is called mesh. One imposes to the mesh elements properties of the materials in the real model;

- Definition of the Environment: in that phase of the process, it is imposed to the model the same boundary and loading conditions that one wants to study in the real model;

- Analysis: one calculates the results (displacements, stresses deformations or other variables of interest), that is, the responses of the model of the structure to static, dynamic or thermal loading;

- Verification of the results: one compares the results with the design admissible limits. If the structure seems to be reliable, one can simply present the results as a table, graphic or visualization in programs of graphical presentation. In case of the development of a new structure, one can then, redesign, adjusting its characteristics till getting satisfactory responses regarding to the specifications.

4.2 Stress analysis

In the present study, the stresses were the results of interest. In the context of the developed model, i.e., a tri-dimensional mesh composed of tetra, penta and hexagonal elements, the knowledge of the stresses permits an evaluation both qualitative and quantitative, of the degree of loading to which each volumetric element, osseous or prosthetic, is submitted.

However, the stress analysis obtained by the processing of the finite elements model it is not something easy to be interpreted: the results obtained by the program of finite elements are stresses of tension, compression and shearing in the axes Z, Y, and X (because of the tri-dimensional modeling) for each one of the elements that composes the mesh.

One way of showing all stresses that act upon an element of the mesh is the use of the Criterion of the Principal Stresses of von Mises.

The analyses of structures, both natural or artificial, have as one of its goals to predict, with a certain degree of probability, the maximum strength of that structure, when subject to a given loading.

In the triple state of stresses, the equilibrium occurs in the tri-dimensional space, and a generalization of the strength criterion should contemplate the three normal principal stresses that act upon the element.

4.3. Computational Support.

4.3.1 Software

MSC/XL

MSC/XL[33] is a software developed by The MacNeal-Schwendler Corp., designed specifically to the preparation of data to the MSC/NASTRAN[31, 32] and analysis of its results. It provides, through graphical interface compatible with the environment of workstations, to develop all phases described in the creation of the finite elements model, except the analysis. Its scope is, thus, pre and post-processor for MSC/NASTRAN.

MSC/NASTRAN

MSC/NASTRAN is a software of The MacNeal-Schwendler designed to solve structural problems described by finite elements models. The acronym NASTRAN derived from “NAsa STRuctural ANalyses”, preserves the origin and its basic objective, i.e., the analysis of structures developed by NASA, its rockets and artificial satellites. Its scope, however, was greatly improved, once that the method that it uses, finite elements, was found extremely adequate to the analysis of a wide range of structures, from problems in heavy mechanics till simulations of odontological osseous systems.

Its algorithms allow the evaluation of structural responses due to static loading (inclusive thermal), the verification of its modes of vibration, its dynamic behaviour in response to forced vibration, both in the linear and non linear context of loading and materials, in steady state, or in transient. In addition, evaluations of the possibilities of structural optimization, i.e., keeping the integrity of the structure with the use of less material or better dynamic performance, can be counted among the highest points in the software.

4.3.2 Equipment

A workstation Hewlett-Packard, model 9000/730, with operational system HP-UX 9.01, 64Mbytes of RAM memory and a tape unit DAT, was the main platform of work. Secondary accesses to its system were an X terminal, also HP, and a personal microcomputer 486DX2, with 8 Mbytes of RAM memory, network board and emulation of X terminal through the software DESQview\X.

All that equipment (and the programs mentioned in the previous item), property of the Instituto Nacional de Pesquisas Espaciais in São José dos Campos, and in the Department of Space Mechanics and Control, was used in a context of academic cooperation and incentive to multi-disciplinar research.

Workstations at Compugraf Tecnologia e Sistemas were also gently offered, before April/1995, while the Instituto Nacional de Pesquisas Espaciais (INPE) did not have the software MSC/NASTRAN operational nor space enough in disk for the analysis of a model of such magnitude.

4.3.4. Description of the model

The majority of the works, using finite elements method with the purpose of studying the stress distribution transmitted to the bone with osseointegrated implants, was done according to bi-dimensional models. The authors that use that methodology believe that the clinical situations can be well represented through those types of models. However, ISMAIL et al[14] (1987) compared the results from bi and tri-dimensional models, representing the same clinical situation. According to the authors, the results from both models presented different values of stresses and also difference in the proportion between the stress values and the direction of the load.

In view of those results, three-dimensional modeling was chosen.

From a real mandible, containing six 17 mm Branemark implants, configured symmetrically in the inter-mentonian region that support a metal-ceramic prosthesis (extended from the first left molar to the first right molar), the finite elements model was developed.

The real geometry, both in the mandible and in the implants and prosthesis, was idealized through tri-dimensional finite elements (Figure 1). Some simplifications, considered not much impacting in the qualitative stress analysis, were done:

- suppression of the coronoid process (secondary apices in the posterior region of the mandible, near the condyles)**,** according to the figure;
- mandible transversal section approximated by linear boundaries, as is shown in Figure 2;
- choice of perfect symmetry with respect to the sagital (vertical simmetry) plane;
- medium line of the inter-mentonian region with constant radius;
- medium line of the mandible body linear ascending with 5.6 degrees;

- medium line of the ascending branch linear with slope of 50.1 degrees;
- oblique internal line represented by transversal constant section;

the condyles were modeled between two vertical planes parallel to the plane XZ by juxtaposing a triangular oblique prism to a prismatic oblique profile approximately rectangular, assigned to the section of the mandible.

The resulting model is composed of 12467 nodes, 54 tetragonal, 2740 pentagonal and 9122 hexagonal elements. The calculated mass of the model is 70 grams.

The properties of the materials in the model are presented in the Table 1.

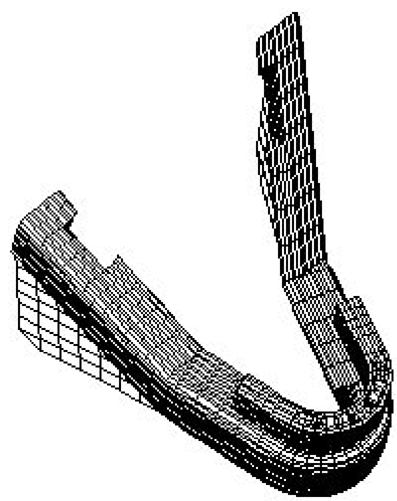

Figure 1 - Complete view of the model that represents the mandible containing the prosthesis supported by implants

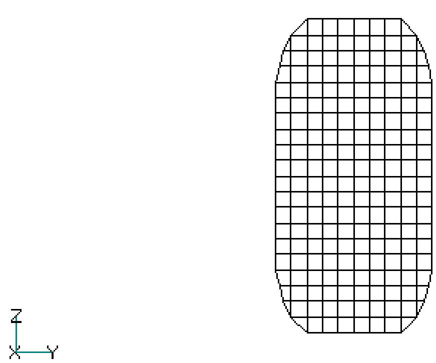

Figure 2: Mandible transversal section

	Cortical bone	**Spongy bone**	**Titanium**	**Gold ceramic**	**Porcelain**
Young's Modulus	13 700 N/mm^2	1370 N/mm^2	103 400 N/mm^2	100 000 N/mm^2	67 700 N/mm^2
Poisson's Coefficient	0.3	0.3	0.35	0.3	0.35
Density	4.5 10-7 kg/mm^3	1.0 10-7 kg/mm^3	4.5 10-6 kg/mm^3	1.93 10-5 kg/mm^3	5.56 10-6 kg/mm^3

TABLE 1 - Material properties

4.3.4.1 Dimensions of the mandible and its components

- Distance inter-condyle 98 mm
- Length 89 mm
- Height 73 mm
- Height of the anterior portion 20 mm
- Width of the anterior portion 10 mm
- Length of the center line of the body 32 mm
- Length of the center line of the branch 68.3 mm

4.3.4.2 Dimensions of the implants and of the prosthesis

- Implants

Length	17 mm
Diameter	3.75 mm

- Abutment

Length	5 mm
Diameter	4 mm

- Prosthesis

Height distance (cervical-occlusal) 10.15 mm

Extremity free	17.3 mm
Ratio power/resistance of arm	17/12.4 mm

4.3.5. Boundary conditions and applied loading

The simulations studied - Canine guide and Balanced Occlusion - were done through different boundary conditions applied to the described finite elements model:

4.3.5.1. Canine guide

The nodes in the imaginary line that passes through the center of the condyles were considered free to rotate only in the X axis. So, the movements of opening and closing of the mandible were simulated, having as fulcra the center of the two condyles.

The node 10260, corresponding to the edges of the cusp of the canine at the working side, was clamped in the Y axis, having, consequently, freedom of rotation in the axes X and Z. Thus, it was simulated the contact of the cusp of the canine at the working side, guiding alone the movement of closing of the mandible to the centric position.

4.3.5.2. Balanced Occlusion

As in the situation of Canine guide, the nodes in the imaginary line, that passes through the center of the condyles, were considered free to rotate only in the X axis.

To simulate the contacts simultaneous of the canine, premolars and first molar at the working side, as well as of the premolars and first molar of the balancing side, the same type of constraint applied to the canine, in the case of Canine guide, was applied to the other teeth. Being so, one tried to simulate the contact of those teeth during occlusal pattern of balanced occlusion, as described in the literature.

In both situations, the presence of food in the working side, during the mastication cycle was simulated. That simulation was done by means of "springs" applied in the nodes corresponding to the bottom of the fosse of the premolars and the first molar at the working side. Each one of those four springs had the coefficient of 175 N/mm, both in the X and Z axes. The value of that coefficient simulates the food resilience as suggested by KREGZDE[19] (1993).

In both situations, the forces applied to the model were equal, trying to simulate the action of the muscle Masseter. Based in the work of HARALDSON; CARLSSON[10](1977) that established the force of the bite as being 50 N in patients using prosthesis supported by implants, during mastication cycle, 20 points at the bottom of the mandible body were taken, 10 at each side, and applied in each one a 2.887 N load. The 20 vectors corresponding to the application of the forces were parallel and directed to the anterior region of the mandible, with an angle of 30 degrees. Thus, one tried to represent the direction of insertion of the beams of the Masseter, acting in the boundary of the mandible and pulling it upwards during mastication cycle. The decomposition of each one of those vectors shows the values of 1.44N and 2.5 N to the axes Y and Z, respectively.

5. Discussion of the Results

The analyses considered a mandible containing six implants in the inter-mentonian region, that supports a metal-ceramic prosthesis. To better understand the analysis, 14 cross-sections in the inter-mentonian region of the finite elements model were selected, in each of the situations proposed in this study: the first, parallel to the horizontal plane, in the height of the implant's necks; the second, also parallel to the horizontal plane, two millimeters above the bottom of the mandible; and twelve vertical cross-sections were done, coinciding with the main axis of the implant, exposing the interface bone-implant, both in mesial and distal sides (Figure 2).

As shown in the literature review, various authors, between them HASSELER et al[12] (1977); RIEGER et al[37] (1990); MEIJER et al[27] (1993), intended to avoid stress concentration along the bone with implants, and the consequent osseous reabsorption. However, the physiology of that phenomenon is not well known yet. It is known that there exists a range of stresses where the bone presents a dynamic equilibrium of apposition and osseous reabsorption (WOLFF et al[51] (1990)). However, the value of that range of stresses is not known. In view of that, the works of research intended to perform qualitative stress analyses, giving less importance to the quantitative results. Therefore, our work also stressed the qualitative aspects, often expressed in percentages, once that the quantitative aspects do not have much clinical meaning.

For a clearer understanding of the results, the implants were numbered from one to six, in the center line of the mandible, respecting the order of generation in the finite elements model, as shown in the Figure 3.

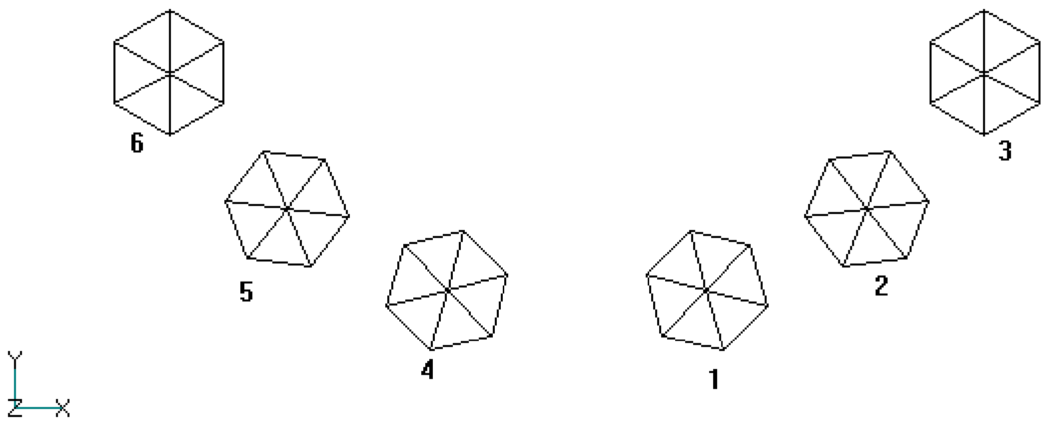

Figure 3: Implant numbering

Figure 4 shows the results for the canine guide clinical situation, from an upper view of the mandible inter-mentonian region. That view shows, globally, the stresses generated in the bone around the neck of the six implants. Analyzing that figure, higher concentration of von Mises stresses in the bone with implants that are in the mandible working side can be observed.

The best proof the observation just mentioned is found in the portion of bone containing distally the implant 3, that presents stresses in the range from 10.53 to 7.02 N/mm^2, while the implant 6, positioned symmetrically to the number 3, but in the balancing side, presents von Mises stresses 55% lower, between 4.68 and 2.35 N/mm^2, in the same osseous region.

It is also noted, the inequality in stress distribution around those two implants. In the implant 3, they take anterior direction, going to the vestibular portion of the cortical mandible bone. By its turn, in the implant 6, those stresses, quite lower, concentrate around it.

It was verified in addition, in the Figure 4, that the stress in the bone containing the six implants decreases, as one goes from the implant 3 to the implant 5, and increases again in the osseous portion around the implant 6.

With respect to the implants 2, 1, 4 and 5, the vestibular portion of the bone around their necks is the most loaded. That portion of the bone around the implant 2 shows 4.68 N/mm^2, close to the surface of the implant, decreasing to 1.18 N/mm^2, while one moves away. The same phenomenon occurs in the implants 1 and 4, but with stresses in the range from 3.51 to 1.18 N/mm^2. In the same region, the implant 5 presents stresses of the order of 1.18 N/mm2. When one gets closer to the implant 6, the stress levels return to the values between 3.51 and 1.18 N/mm^2.

Figure 5 shows the results for the balanced occlusion clinical situation in the inter-mentonian region. Analyzing the behaviour of von Mises stresses in that figure, it is observed that the working side presents a stress concentration slightly higher that the balancing side. That observation is explained by the presence of the simulated food, in the posterior region of that side of the mouth, done through springs placed in the model. Also in that situation, the distal portion of the bone around the implant's neck number 3 was more loaded, with stresses between 8.33 the 6.48 N/mm^2; while in the same region around the implant 6 those stresses were 22% lower, in the range from 6.48 to 3.71 N/mm^2.

That observation gives us evidences of a more homogeneous stress distribution between the implants in the case of balanced occlusion, when compared with the canine guide. In spite of stress peakes observed in both cases in the same place - distal portion of the bone around the implant 6 - in the case of balanced occlusion, that peak was 21% lower than in the case of canine guide (10.53 and 8.33 N/mm^2).

In Figure 5, it is observed, in addition, that the vestibular portion of the cortical bone around the implant's necks continues to be the most loaded. In that region, the stresses starting at 3.71 N/mm^2 around the implant 2, decrease till the value of 0.93 N/mm^2 close to of the implant 5, increasing again around the implant 6. This phenomenon showed similar results as the situation of canine guide, but with a homogeneity in the stress distribution slightly higher in balanced occlusion.

So, as in the case of the canine guide, the vestibular portion of the cortical bone, around the implants' necks numbers 2, 1, 4 and 5, was more loaded, when compared to the vestibular portion: in the implant 2, values of 3.71 N/mm^2 close to the surface of the piece are found, decreasing as one goes in direction to the mandible vestibular boundary, attaining the value of 0.93 N/mm^2. In the implants numbered 1, 4 and 5, that phenomenon is observed with the range of stresses between 2.78 and 0.93 N/mm^2. When one gets closer to the implant 6 those stresses return to the range from 6.48 to 0.93 N/mm^2.

A more careful observation of the stresses in the distal portion of the bone around the implant's neck number 3, in both cases analyzed, presents very interesting results. In both models, it is the most loaded osseous region, although as previously described, in the situation of canine guide it is significantly higher than in balanced occlusion: 10.53 and 8.33 N/mm^2 respectively. However, there exists a significant difference in the localization of the most loaded region: in the case of the canine guide, it follows a triangle with vertex directed to the mandible vestibular boundary, while in the balanced occlusion, the vertex of the triangle points to the distal. It is observed also, in both cases, that the distribution of those stresses takes the direction of the external oblique line.

Figure 6 shows the results for the canine guide clinical situation, according to a cross-section 2 mm above the bottom of the mandible. That view shows, globally, the stresses generated in the portion of the cortical bone where the apex of the implants is simply supported. This cross-section, in that region of the mandible, is important to observe the part of the stresses transmitted to the cortical bone through the apex of the implants.

It can be noticed that the cortical bone that supports the implant 3, presents higher stress levels of von Mises in the portions of the cortical bone that support the other implants. That stress was 66 % higher than in other regions of that figure. It is observed a homogeneity of stresses in the bone below the other implants.

Figure 7 shows the results for balanced occlusion, on a cross-section 2 mm above the bottom of the mandible.

As observed in Figures 1 and 2, the simulation of balanced occlusion presented more homogenous stress levels. The portion of the cortical bone around the implant 3, remained more loaded, but then, with levels 33 % higher than of the other ones. This fact is explained by the increase of the stress level around the implants 6 and 5, absorbing larger portion of the mastication loads.

It can be concluded, in addition, that in spite of the high increase of stress noticed in the bone close to the implant 3, in the case of canine guide, and of the implants 3, 5 and 6 for balanced occlusion, most of the mastication loads are absorbed by the cortical bone around the implants' necks.

Analyzing, then, the stress distribution, separately, in each implant, through a section in the model, along the axis of each one of the implants. Each section produce two views, one mesial and the other distal, of the interface bone-implant.

The Figures 8a and 8b show graphically von Mises stress distribution in the bone around the implant 1, for canine guide simulation.

By the observation of the Figures 8a and 8b, it is verified that the lower von Mises stresses - 0.03 N/mm^2 - occur in the portion of the spongy bone containing the apical third part of that implant. Going through that interface occlusally, the stresses increase, till getting the maximum value registered for that implant - 4.79 N/mm^2 - in the vestibular portion of the cortical bone around its neck. As will be shown in other implants, that portion of bone will always be the most loaded. Analyzing still, the Figures 8a and 8b, it is noticed that the cortical bone in which the apex of the implant is supported presents a slight increase of stress - 0.50 N/mm^2 - when compared to the portion of spongy bone just above it.

If one compares the Figures 9a and 9b with the two previous figures, it will be noticed great similarity between them. That occurs once, according to a qualitative analysis, von Mises stress distribution is very similar in both cases. The differences noticed occur only in the stress levels. Thus, the portion of cortical bone around the implant's neck remained more loaded - 3.89 N/mm^2 - but with values 18.79% lower than the case of canine guide. The lower portion of the cortical mandible bone, interface with the implant bottom, presented values of the order of 0.41 N/mm^2, 18% lower than the simulation of canine guide.

The analysis of the layer of cortical bone around the implant 1 indicates the existence of a slight stress concentration in its lingual inferior portion, in both situations simulated. The difference happens only in the values of those stresses: 0.98 N/mm2 in the situation of canine guide, 0.41 N/mm2 in balanced occlusion, representing a difference of 58%.

Although, in the case of canine guide, the calculated stresses along the bone around the implant 1, should be considerably higher than those calculated in the case of balanced occlusion, the stresses keep the same proportionality. Having compared the differences of stress between the apex and neck regions in a given implant, in both situations, it will be noticed that there were no significant differences. In the case of canine guide, the region of the implant's neck presented maximum stress of 4.79 N/mm^2, and the region of the apex presented maximum stress of 0.5 N/mm^2; 89% lower. In balanced occlusion, those values, as already mentioned, were 3.89 and 0.41 N/mm^2 in the osseous regions of the neck and apex of the implant, respectively, what gives us the same difference around 89%.

The Figures 10a and 10b show von Mises stress distribution, in the bone around the implant 2, for canine guide simulation.

The von Mises stress distribution in the bone around the implant 2, in the situation of canine guide, was similar to the observed for the implant 1. The peak of stress, again happened in the portion of the bone around the implant's neck - 4.99 N/mm^2 - having a decrease of that stress, as one goes to the apex of the implant. The portion of the cortical bone around the apex of the implant presented von Mises stresses around 1.5 N/mm^2; 6.9% lower than the peak of calculated stresses in the portion of the cortical bone around the neck of that implant. The spongy bone, again showed very low values, between 0.09 and 0.83 N/mm^2.

Figures 11a and 11b show von Mises stress distribution, in the bone around the implant 2, for balanced occlusion simulation.

Having undergone the simulation of balanced occlusion, the implant 2 also presented its peak of stresses in the upper vestibular portion of the cortical bone - 3.74 N/mm^2 - but 25% lower that in the simulation of canine guide. Analyzing the Figures 11a and 11b, it is noticed that von Mises stresses decrease, as one goes to the apex of the implant, till getting values around 0.45 N/mm^2. Again the stresses increase close to the cortical bone and the apex of the implant - 1.19 N/mm^2. This value is 20% lower than the same region presented in simulating the canine guide and 68% lower that the peak of calculated stresses in the same simulation of balanced occlusion.

So, as in the implant 1, the qualitative analyses of von Mises stress distribution presented similar results in both situations. For that implant, the differences between the calculated stresses in the bone around the neck and the apex, in both situations, were identical, around 69%.

The Figures 12a and 12b show von Mises stress distribution, in the bone around the implant 3, for canine guide simulation.

The analysis of the Figures 12a and 12b indicates a significant difference in the qualitative analysis of von Mises stress distribution, in the bone around the implant's neck number 3, when compared to both previous implants. For that implant, stress peakes was also observed in the upper portion of the cortical bone around the implant, but, contrarily to what was previously observed, that peak - 11.69 N/mm^2 - is not found anymore in the vestibular portion of the implant, but in its distal portion. This phenomenon is justified by the load imposed, mainly to that implant, by the free arm of the prosthesis. As a consequence, that one is also, the most loaded region of the entire model of the mandible. For that reason, according to our understanding, that should be the critical area in terms of probability of failures in a mandible with prosthesis totally supported by implants. That stress, as discussed by RANGET et al[36] (1989) will be higher, as is increased the free arm of the prosthesis. Thus, the authors do not recommend free arms longer than 20 mm.

Following the interface formed between the bone and the implant, apically, it is noticed that the stress distribution for that implant is similar to the other cases; the stresses decrease, till getting the apical portion of the cortical bone, where they present a slight increase - 2.39 N/mm^2.

The Figures 13a and 13b show von Mises stress distribution, in the bone around the implant 3, for balanced occlusion simulation.

The comparison between the results presented by the Figures 13a and 13b, and 12a and 12b shows results similar to the implant 3, in both situations simulated. The portion of the cortical bone that interfaces with the apex of the implant presents stress values of the order of 1.9 N/mm^2, 20% lower that in the situation of canine guide in the same region.

As one goes to the upper portions of bone, the stress values increase, till the value of 9.25 N/mm^2. So, as in the case of canine guide, that peak of stress, in spite of being 21% lower, occurred distally, differently of what was observed in the implants 1 and 2.

So, as in the simulation of the canine guide, that osseous portion was the most loaded of the entire the model of simulation of balanced occlusion. The fact that stress is 21% lower, in comparison with the canine guide, indicates that the occlusal pattern of balanced occlusion offers a higher margin of safety. In other words, the change from occlusal pattern to balanced occlusion, lowered in 21% the stress from the most critical point, as already discussed, in the finite elements model.

It can be concluded, in addition, that in the qualitative aspect, the four illustrations regarding to the implant 3 do not present significant differences.

In what follows, the results around the three implants of the balancing side are presented.

The Figures 14a and 14b show von Mises stress distribution, in the bone around the implant 4, for canine guide simulation.

That figure presents a stress distribution, in that implant, similar to the observed in the other ones. The upper vestibular portion of the cortical bone around the implant's neck, was again the most loaded, presenting peak of von Mises stresses equal to 2.83 N/mm^2. Those stresses decrease, as one moves apically, till values of 0.32 N/mm^2, increasing again in the lower portion of the cortical bone up to 0.60 N/mm^2.

As observed in the other cases, it is noticed a slight increase of stress in the lower vestibular portion of cortical bone containing that implant, up to 0.60 N/mm^2.

The Figures 15a and 15b show von Mises stress distribution, in the bone around the implant 4, for balanced occlusion simulation.

The analysis of the results shows that, contrarily to the observed in the implants positioned in the mandible working side, the stresses observed in this implant was higher than those in the simulation of balanced occlusion. In spite of stress peakes continuing to occur in the same region of the bone around the implant's neck - 3.43 N/mm^2 - now, in balanced occlusion, that was 17 % higher than in case of canine guide.

In the same way, von Mises stresses calculated in the lower portion of cortical bone of that implant - 0.72 N/mm^2 - were 16% higher that in the simulation of canine guide.

It is noticed also that the area of stress concentration in all implants, in the lingual side of the cortical bone, was 20% higher than the observed in the situation of canine guide.

It could be observed then, as in the other implants, that the difference between the calculated stresses in the bone around the neck and the apex of that implant, kept the same proportion in both situations simulated, 78%.

The Figures 16a and 16b show von Mises stress distribution, in the bone around the implant 5, for canine guide simulation.

A more careful analysis of the Figure 16b shows an interesting phenomenon in von Mises stress distribution in the implant 5, for canine guide simulation, that was not observed in the other analyses. The peak of stress, common to all individual analyses of implant, in the cortical bone around the implant's neck, in this case, was divided in two points around the neck. Two different regions can be noted, showing that the stress was better distributed around the implant. As a consequence, there was a decrease in the stress peak, when compared to the other implants, 1.84 N/mm^2, 34% lower that in the implant 4.

As in the other implants, the stress decrease, as one goes to the apical portion of the implant, returning to the levels of 0.64 N/mm^2, when getting the bottom of the cortical bone.

The analysis of those two Figures shows, also, a difference of the implant 5, with respect to the other ones. The zone of stress of the inferior lingual vestibular portion of the cortical bone, that appears in all implants, in this case showed wider, with values between 1.1 and 0.76 N/mm^2.

The Figures 17a and 17b show von Mises stress distribution, in the bone around the implant 5, for balanced occlusion simulation.

The qualitative analysis of von Mises stress distribution around the implant 6, for balanced occlusion simulation, followed the pattern presented by the other ones. It is observed the peak of the stresses in the upper vestibular portion of the cortical bone around the implant's neck - 3.51 N/mm^2 - 48% higher than the value calculated in the same region for canine guide simulation. That observation confirms the tendency observed in the analysis of the implant 4, where the implants of the balancing side are more loaded during lateral movements, than the implants at the working side.

That stress, as already expected, decreases, as one goes to the apex of the implant, down to 0.05 N/mm^2.

The portion of lower cortical bone, where the apex of the implant stands, presents von Mises stresses equal the 0.74 N/mm^2; 14% higher than in case of canine guide.

Analyzing the difference between the calculated stresses in the bone around the neck and the apex of the implant 5, it was noticed by the first time, that it did not keep the same proportion in both cases. In the case of canine guide, the stress calculated in the region of the bone around the implant's neck was 65% higher than that of the cortical bone in which the apex is supported, and in the simulation of canine guide, that difference was 78% higher.

That observation could perhaps be explained by the better distribution of stress in the bone around the implant's neck number 5, during case of canine guide. With that, stress peakes of that region decreased and, consequently, also its difference of stress with respect to the bone that supports the apex of that implant.

The Figures 18a and 18b show von Mises stress distribution, in the bone around the implant 6, for canine guide simulation.

The qualitative analysis of von Mises stress distribution in the implant 6, in the simulation of canine guide, presents a difference with respect to the localization of stress peakes that has occurred in the portion of the bone around the implant's neck. This peak of stresses, that to the implants of number 1, 2 and 4 occurred in the vestibular portion, in the implant 6, as observed in the implant 1, occurred in the distal portion of the implant. This phenomenon is explained by the loading imposed by the free arm of the prosthesis, to those two implants. The form of minimizing that overloading was already discussed, when analysing the stress distribution around the implant 3. The value of that stress calculated in the implant 6 was of 4.39 N/mm^2.

Another fact worth of notice, as to the stress distribution, is the absence of the area of load concentration in the lower lingual portion of the cortical bone around that implant. That could perhaps be explained by the distal position of that implant in the arc.

The spongy bone around the implant was again not much loaded, presenting stresses around 0.89 N/mm^2. The portion of cortical bone that receives the apex of the implant presented von Mises stresses equal to 0.90 N/mm^2.

The Figures 19a and 19b show von Mises stress distribution, in the bone around the implant 6, for balanced occlusion simulation.

As in the case of canine guide, that implant presented stress peakes - 7.06 N/mm^2 - in the cortical bone around the implant's neck, displaced distally. That stress was 38% higher than the observed in the same region in the simulation of canine guide.

The stress observed in the cortical bone where the apex of the implant is simply supported was of 1.44 N/mm^2; 38% higher than in the same region when undergone to the canine guide simulation.

So as in the case of canine guide, it is noted the absence of the area of load concentration in the lower lingual portion of the cortical bone of that implant. That fact stresses the hypothesis that it is due to the implant position in the arc.

For the implant 6, the difference between the calculated stresses in the bone around the neck and the apex of that implant showing the same proportion; 79% in both simulations.

During both simulations in the six implants, the portions of the cortical bone around the implant's necks were the most loaded. That observation agrees with those already shown by KITOH et al[18] (1980), BORCHERS; REISCART[4] (1983), FRENCH et al7 (1989), MATSUHITA et al[23] (1990), TORTAMANO[48] (1992).

Those authors also corroborate our opinion in what the spongy bone has little participation in the absorption of the mastication loads.

The cortical bone that supports the apex of the implants had a significant increase in stresses, in all implants, indicating that it participates in the absorption of the loads transmitted by the prosthesis.

Analyzing the results, it is clearly noted that, in both simulations, canine guide and balanced occlusion, the bone with implants in the mandible working side is more loaded than the bone with implants in the balancing side.

Comparing the stress levels calculated in the bone around the implant's necks, once that this is the one that absorbs the more significant portion of the loads applied on the prosthesis, it can be concluded that during balanced occlusion there was a more homogeneous stress distribution, for, in the situation of simulation of canine guide, the difference between the maximum and minimum stresses was quite larger.

However, that conclusion is not sufficient to indicate balanced occlusion as the elected occlusal pattern for that type of prosthesis, once that just biomechanical aspects were taken into account for those two occlusal patterns. Aspects as properception (tooth tact), muscular force, type of antagonistic teeth and protection of the temporal-mandibular articulation against possible interferences, that were not objective of our work, should have been taken into account. Other studies will be added the this one, to a definitive positioning concerning the occlusal pattern adequate to prosthesis supported by implants.

It is worth stressing, in addition, that the Finite Elements Method is a helping research tool. Being so, that methodology, although not producing definitive results, will certainly help to preview the natural phenomena inside the bodies in study, should they be alive or created by the man. It is our hope that the results of that work provide some subsidy to people interested in that field of the Odontology and serve also to guide future researches, in their search of science perfection.

6. CONCLUSIONS

Based in the results, and according to what was already explained, it can be concluded that:

- Both in the balanced occlusion clinical situation, and in the canine guide, a higher concentration of von Mises stresses in the bone with implants that are in the mandible working side was observed.

- The stress distribution was more homogeneous in the bone with implants in balanced occlusion, when compared with the situation of canine guide. Taking into account, just the biomechanical aspects, balanced occlusion would be more indicated to that type of prosthesis.

- The stress peaks occurred in the distal portion of the bone in both implants positioned backwards in the mandible. The working side presented better stress in the situation of canine guide, when compared to balanced occlusion, while the balancing side presents better stress during balanced occlusion.

- For the four implants situated between the two distal implants, the maximum stress occurred in the vestibular portion of the bone around them.

Bibliography

1. ADELL, R.; LEKHOLM, U.; ROCKLER, B.; BRANEMARK, P-I. A 5-year study of osseointegrated implants in the treatment of edentulous jaw. **Int. J. Oral Surg** v. 10, n. 6, p. 387-416, Dec. 1981.

2. ADELL, R.; LEKLOLM, U.; ROCKLER, B.; BRANEMARK, P-I.; LINDHE, J.; ERIKSSON, B.; SBORDONE, L. Marginal tissue reactions at osseointegrated titanium fix-

tures. I. A three-year longitudinal prospective study. **Int. J. Oral Maxillofac. Surg.,** V. 15, n. 1, p. 39-52, Feb. 1986.

3. BONWILL, W. G. A. Geometric and mechanical laws of articulation. Anatomical articulation. **Trans. Odonto. Soc. Penn**., P 119-133, 1885. Apud MOHL, N. D., ZARB, G. A., CARLSSON, G. E., RUGH, J. D. **Fundamentos de Oclusão:** Rio de Janeiro, Quintessence, 1989 p. 185.

4. BORCHERS, L. & REICHART, P. Three-dimensional stress distribution around a dental implant at different stages of interface development. **J. Dent. Res.** V. 62, n. 2, p. 155-159, Feb. 1983.

5. BRANEMARK, P. I. Osseointegration and its experimental background. **J. Prosthet. Dent.,** V. 50, p. 398-410, 1983

6. D'AMICO, A. The canine teeth: normal functional relation of the natural teeth of man (concluded). **J. S. Calif. dent. Ass.** v. 26, f. 7, p. 239-41, July 1958.

7. FRENCH, A. A.; BOWLES, C. Q.; PARHAM, P. L.; EICK, J. D.; COBB, C. N., KILLOY, W. J. Comparison of peri-implant stresses transmitted by four commercially available osseointegrated implants. **Int. J. Periodont Restorat. Dent.,** V. 9, n. 3, p. 221-229, Dec. 1989.

8. HARALDSON, T. A photo-elastic study of some biomechanical factors affecting the anchorage of osseointegrated implants in the jaw. **Scand. J. Plast. Reconstr. Surg.** V. 14, n. 3, p. 209-214, 1980.

9. HARALDSON, T. Mastication muscle function in patients rehabilitated with OIB. **Swed Dent J, Supplement** v. 28 n. P. 137-142, 1985.

10. HARALDSON, T., CARLSSON, G. E. Bite force and oral function in patients with osseointegrated oral implants. **Scand J Dent Res**., V. 85, n. 3, p. 200- 208, march 1977.

11. HARALDSON, T. & CARLSSON, G.. Bite force and oral function in patients with osseointegrated oral implants. **Scand. J. Dent Res.** v. 85, f. 2, p. 200-208, may 1977.

12. HASSELER, C. R.; RYBICKI, E. F.; CUMMINGS, K. D.; CLARK, L. C. Quantitation of compressive stress and effects upon bone remodeling. **Bull Hosp Bone Joint Res** v. 38, p. 90-93, 1977

13. HOBO, S., ICHIDA, E., GARCIA, L. T. Osseointegrated and occlusal implants rehabilitation. Tokyo, Quintessence, 1989. p 259.

14. ISMAIL, Y. H.; PAHOUNTIS, L. N.; FLEMING, J. F. Comparison of two-dimensional and three-dimensional finite element analyses of a blade implant. **Int. J. Oral Implant.** v. 4, n. p. 25-31, 1987.

15. JEMT, T. Modified single and short-span restorations supported by osseointegrated fixtures in the partial edentulous jaw. **J Prosthet Dent** v. 55 n., p. 243-247, 1986.

16. JERGE, C. T. Organization and function of the trigeminal mesoencephalic nucleus. **J. Neurophysiol**. v. 26, p. 379, 1963.

17. KAWAMURA, Y. Neurophysiologic background of occlusion. **Periodontics**. v. 5, f. 4, p. 175-83, July/Aug 1967

18. KITOH, M.; MATSUSHITA, Y.; YAMAUE, S.; IKEDA, H.; SUETSUGU, T. The stress distribution of the hydroxyapatite implant under the vertical load by the two-dimensional finite element method. **J. Oral Implant**., v. 149, n. 1, p. 65-71, Jan. 1988.

19. KREGZDE, M. A method of selecting the best implant prosthesis design using three-dimensional finite element analysis. **Int J. Maxilofac. Impl. v.** 8, n. 6, p. 662-673, July 1993.

20. LEKHOLM, U clinical procedures for treatment with osseointegrated dental implants. **J Prosthet Dent** v. 50, n. 1 p. 116-120, July 1983.

21. LOPEZ-JIMÉNEZ, V.. Prótesis sobre implantes: Oclusion, casos clínicos y laboratorio. Madrid, 1993 p. 264.

22. MAILATH, G.; STOIBER, B.; WATZEK, G.; MATEJKA, M. Die Knochenresorpion an der Eintristtselle osseointegrierter Implantate-ein biomechanisches Phanomen. Eine Finite-Element-Studdie. **Z. Stomat.,** v. 86, n. 4, p. 207-216, June 1989.

23. MATSUSHITA, Y.; KITOH, M.; MIZUTA, K.; IKEDA, H.; SUCTSUGU, T. Two-dimensional FEM analysis of hydroxyapatite implants: diameter effects on stress distribution. **J. Oral Implant.,** v. 6, n. 1, p. 6-11, Jan. 1990.

24. McGLUMPHY, E. A.; CAMPAGNI, W. V.; PETERSON, L. J. A comparison of the stress transfer characteristics of dental implant with a rigid or a resilient internal element. **J. Prosth. Dent.,** v. 62, n. 5, p. 586-593, Nov. 1988.

25. McCOLLUM, B. B. Considering the mouth as a functioning unit as the basis of a dental diagnosis. **J. Calif. Dent. Assoc**., v. 5, n., p. 268-276, 1938.

26. McCOLLUM, B. B. & STUART, C. E. A research report. California. scientific Press, 1955, Apud THORNTON, L. J. Anterior guidance: group function-canine. a literature review. **J. prosth. Dent.** v. 64, f. 4, p. 479-82, Oct. 1990

27. MEIJEER, H. J. A.; STARMANS, F. J. M.; STEEN, W. H. A.; BOSMAN, F. A three-dimensional, finite-element analysis of bone around dental implants in an edentulous human mandible. **Arch Oral Biol** v. 38, n. 6, p. 491-496, June 1993.

28. MEROUEH, K. A.; WATANABE, F.; MENTAG, P. J. Finite element analysis of partially edentulous mandible rehabilitated with an osseointegrated cylindrical implants. **J. Oral Implant.,** v. 13, p. 2, p. 215-238, Mar. 1987.

29. MIRALLES, R.; BULL, R.; MANNS, A; ROMAN, E. Influence of balanced occlusion and canine guidance on electromyographic activity of elevator muscles in complete denture weares. **J. prosth. Dent**. v. 61, f. 4, p. 494-498, Apr. 1989.

30. MOHL, N. D., ZARB, G. A., CARLSSON, G. E., RUGH, J. D. **Fundamentos de Oclusão.** Rio de Janeiro: Quintessence, 1989. p. 183-199.

31. MSC/NASTRAN Handbook for linear analysis. Los Angeles, MacNeal-Schwendler, 1991.

32. MSC/NASTRAN User's Manual. Los Angeles, MacNeal-Schwendler, 1991.

33. MSC/XL User's Manual. Los Angeles, MacNeal-Schwendler, 1991.

34. NAGAO, M. Comparative studies on the curve of Spee in mammals, with a discussion of its relation to the form of the fossa mandibularis. **J. dent. Res**. v. 1, f. 2, p. 159-202, June 1919.

35. PARKER, M. W. The significance of occlusion in restorative dentistry. **Dent Clin North Am** v. 37, n. 3, p. 341-351, July 1993.

36. RANGERT, B.; JEMT, T.; JORNEUS, L. Forces and Moments on Branemark implants. **Int J. Oral Max Impl.** V. 4, F. 3, P. 241-247, July 1989.

37. RIEGER, M. R.; MAYBERRY, M.; BROSE, M. O. Finite element analysis of six dental implants. **J. Prosthet Dent**. v. 63, n. 6, p. 671-676, June 1990.

38. SCHUYLER, C. H. Principles employed in full denture prosthesis which may be applied in other field of dentistry. **J Am. Dent. Assoc.,** v. 16, n., p. 2045-2054, 1929.

39. SCHUYLER, C. H. Fundamental principles in the correction of occlusal disharmony, natural and artificial. **J. Amer. dent. Ass**., v. 22, f. 7, p. 1193-202, july 1935.

40. SHAW, D. M. Form and function in teeth. Int, J. Orthodont. v. 10, f. 11, p. 703-18, nov 1924

41. SKALAK, R. Stress transfer at the implant interface. **J. Oral Implant.** v. 13, n. 4, p. 581-593, Oct. 1988.

42. SPEE, F. G. The condylar path of mandible along the skull. **Arch. Anat. Physiol**. v. 16, p. 285-294, 1890, Apud **J. Am. Dent Assoc**. v. 100, n. 5, p. 670-675, 1980.

43. STALLARD, H. & STUART, C. E. What kind of occlusion should recusped teeth be given? **Dent Clin North Am**, v., p. 591-606, Nov. 1963.

44. STILLMAN, P. & McCALL, O. **A textbook of clinical periodontia.** N. Y. Macmillan, 1927 Apud WEISGOLD, A. S. Occlusion: review of various concepts. Probe, p. 373-386, mar 1975.

45. STUART, C. E. Why dental restoration should have cusps. **J. Prosthet Dent**, v. 10, n., p. 553-555, 1960.

46. STUART, C. E. & STARLLARD, H. Diagnosis and treatment of occlusal relations of the teeth. Tex. dent. J. v. 75, f. 7, p. 430, July 1957

47. TAKUMA, M.; TSUTSUMI, S.; FUKUNAGA, S.; TAKAMORI, Y.; HARADA, S.; KUROKAWA, F.; TAKASHIMA, F.; MARUYMS, T. Stress distribution around alumina, hidroxyapatite and plasma-sprayed titanium dental implants. **J. Osaka Dent. Univ.,** v. 28, n. 4, p. 73-82, Dec. 1988.

48. TORTAMANO NETO, P. Estudo da distribuição das tensões transmitidas à mandíbula por um implante osseointegrado, variando-se a espessura do osso cortical e a direção da carga aplicada por meio do método dos elementos finitos. São Paulo, 1992. 47p. Tese (mestrado) - Faculdade de Odontologia da Universidade de São Paulo.

49. VALENTIN, I.; TAIEB, A.; FRANQUIN, J. C.; HOURI, A. Analyse de la répartition des contraintes os-implante. Modélisation plane par élements finis. **Cah. Prothese**., v. 72, n., p. 142-153, Dec. 1990.

50. WILLIAMSON, E. H. & LUNDQUIST, D. O. Anterior guide: its effect on electromyographic activity of the temporal and masseter muscles. **J. prosthet. Dent**. v. 49, f. 6, p. 816-23, june 1983.

51. WOLFF, J.; RIEGER, M. R.; MAYBERRY, M.; BROSE, M. O. Finite element analysis of six endosseous implant. **J. Prosthet Dent**., v. 63, n. 6, p. 671-676, June 1990.

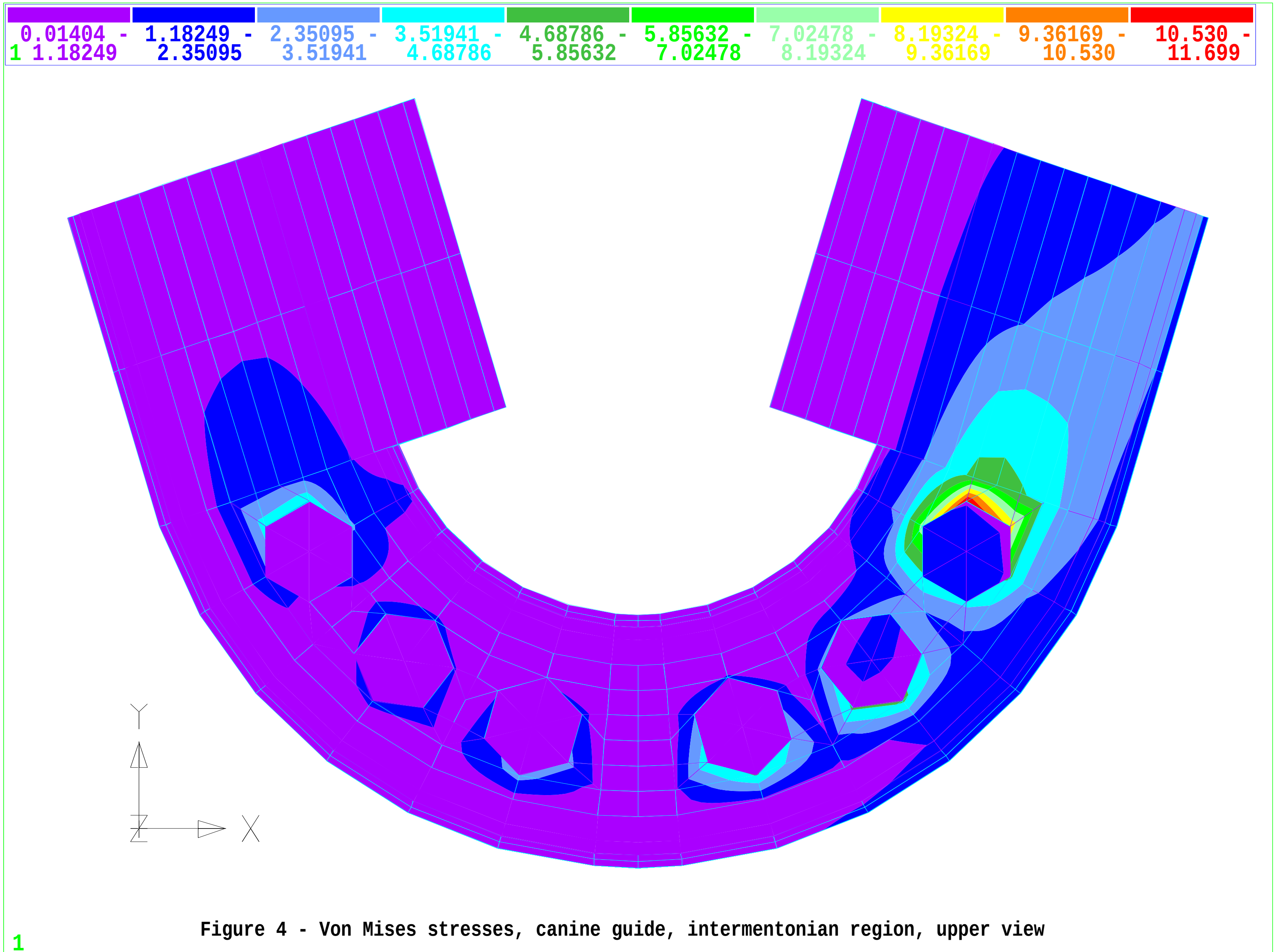

Figure 4 - Von Mises stresses, canine guide, intermentonian region, upper view

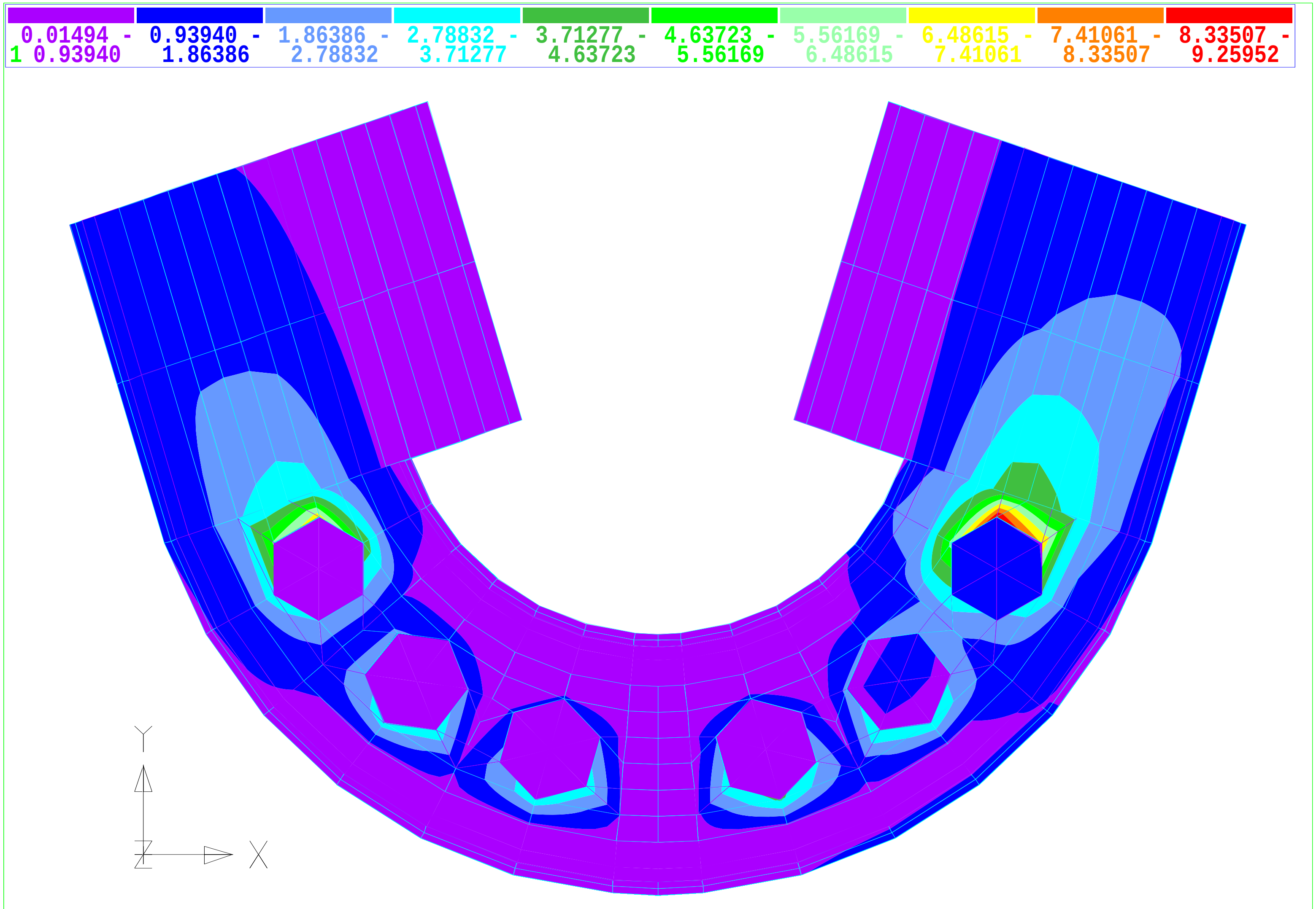

Figure 5 - Von Mises stresses, balanced occlusion, intermentonian region, upper view

1

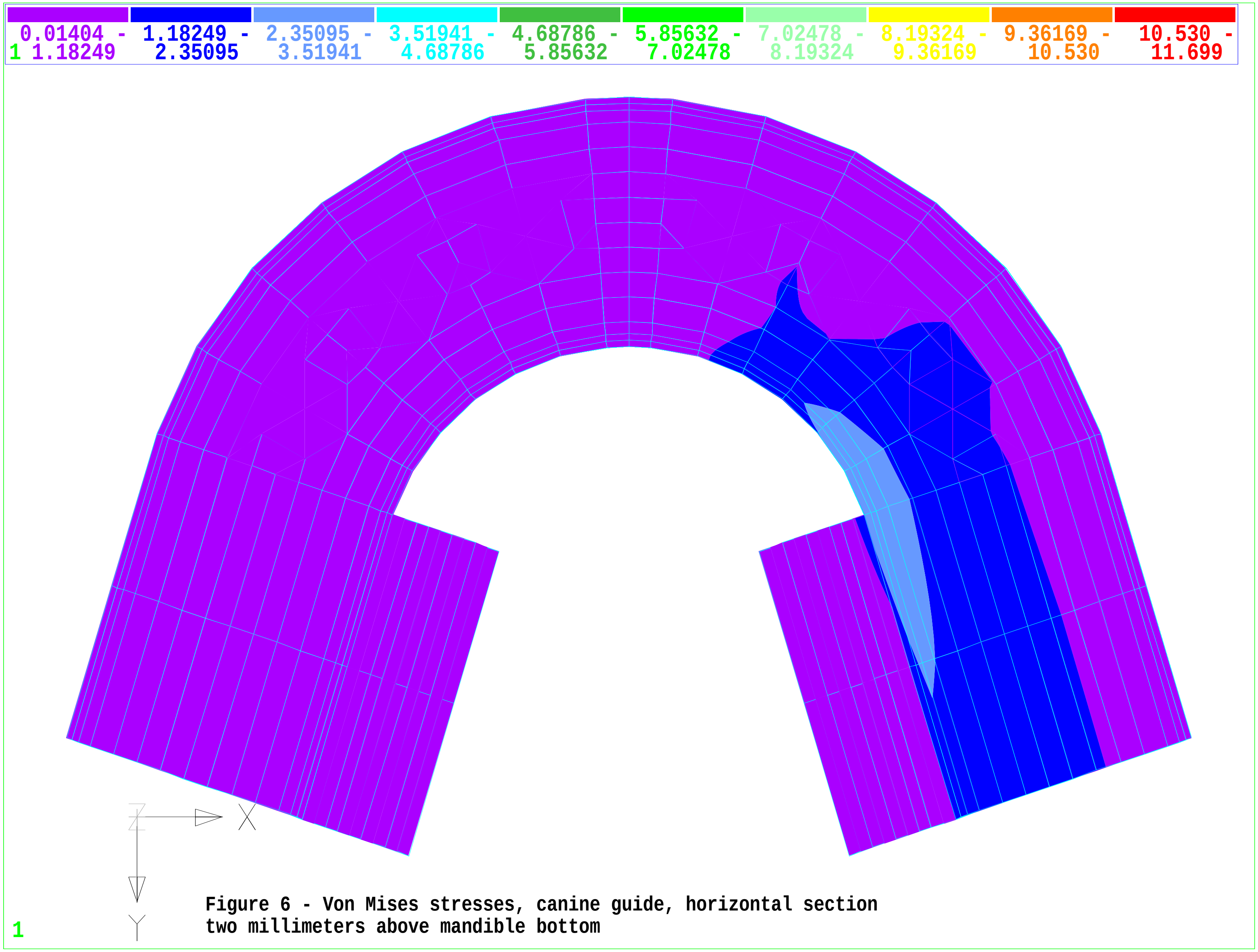

Figure 6 - Von Mises stresses, canine guide, horizontal section two millimeters above mandible bottom

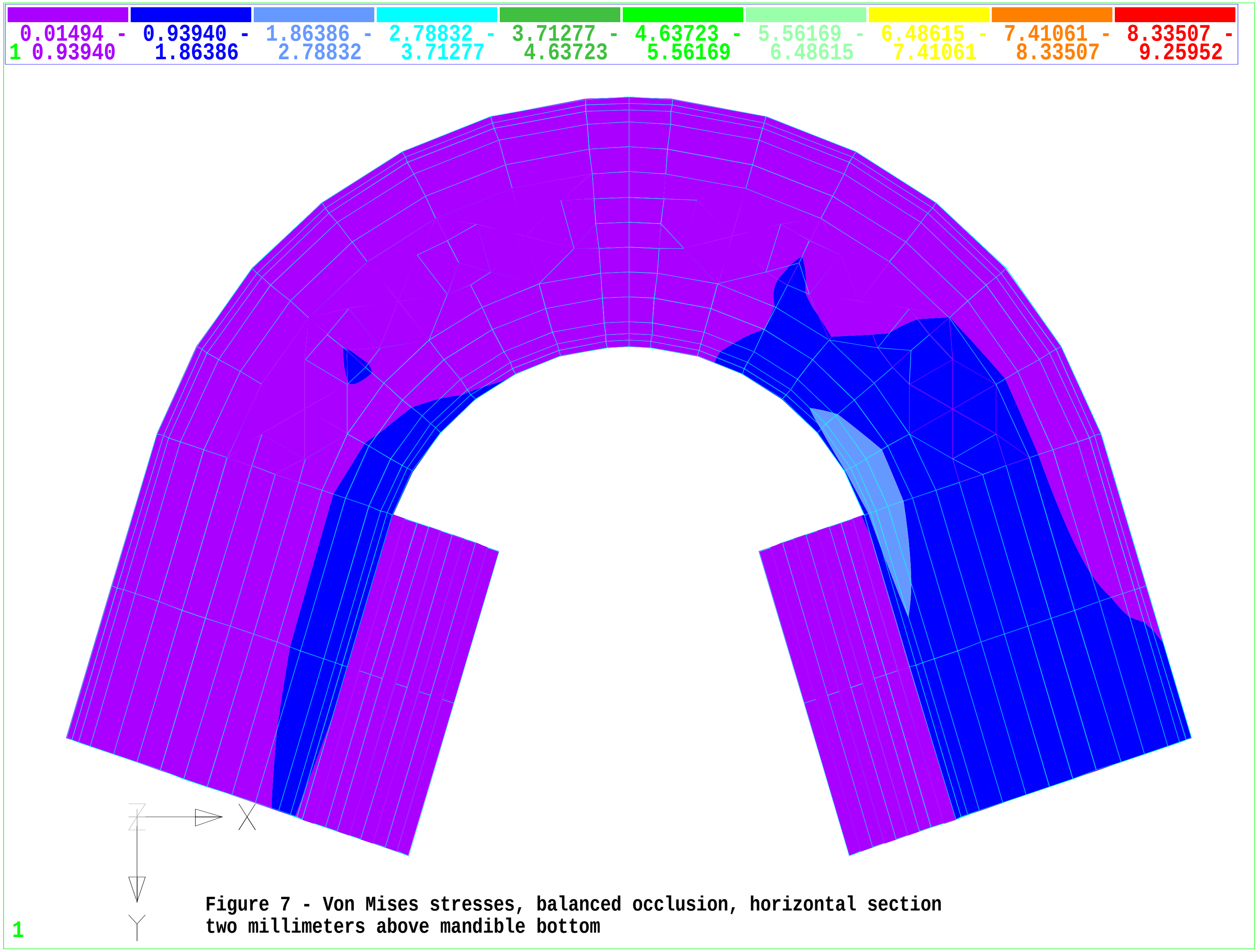

Figure 7 - Von Mises stresses, balanced occlusion, horizontal section
two millimeters above mandible bottom

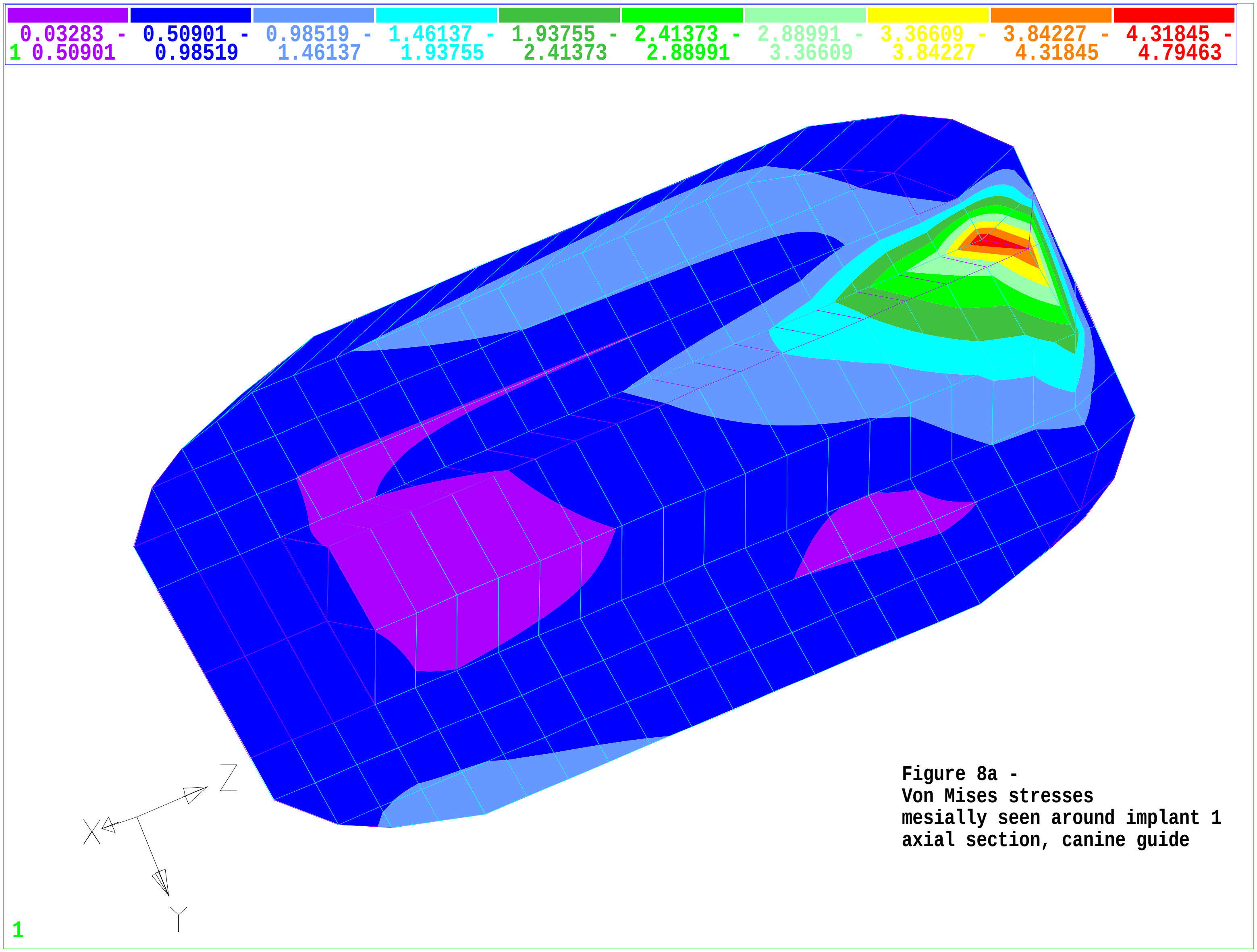

Figure 8a -
Von Mises stresses
mesially seen around implant 1
axial section, canine guide

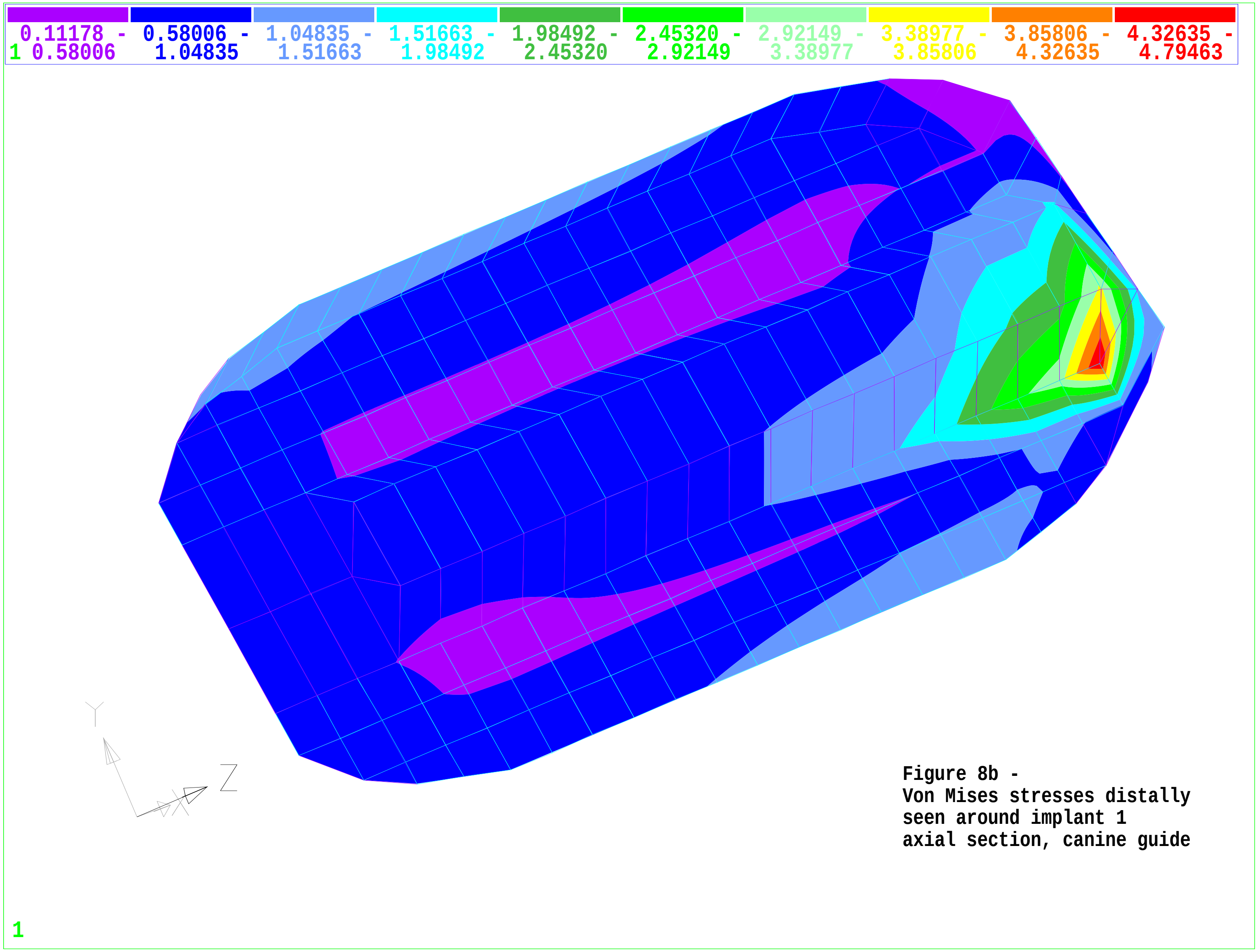

Figure 8b -
Von Mises stresses distally
seen around implant 1
axial section, canine guide

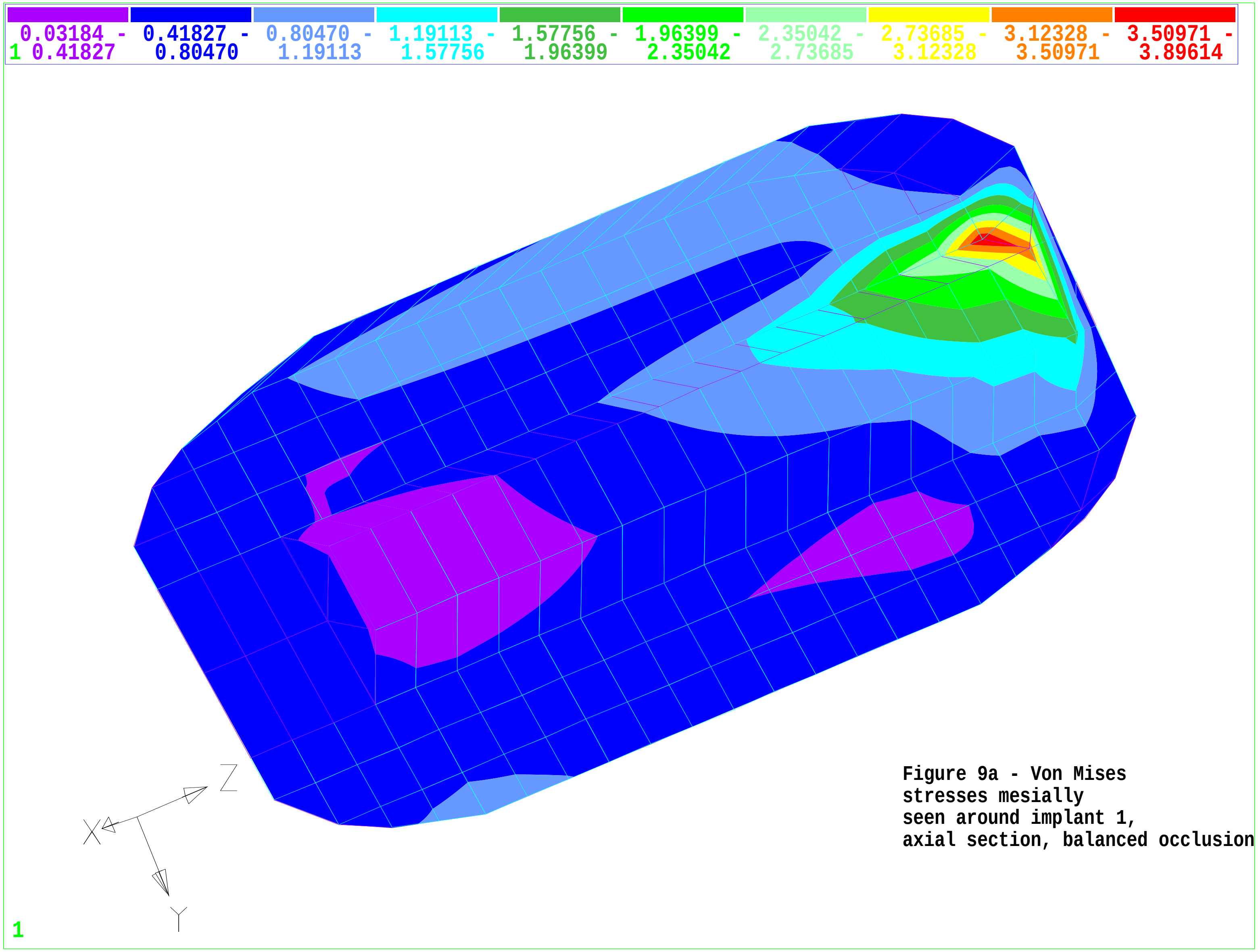

Figure 9a - Von Mises stresses mesially seen around implant 1, axial section, balanced occlusion

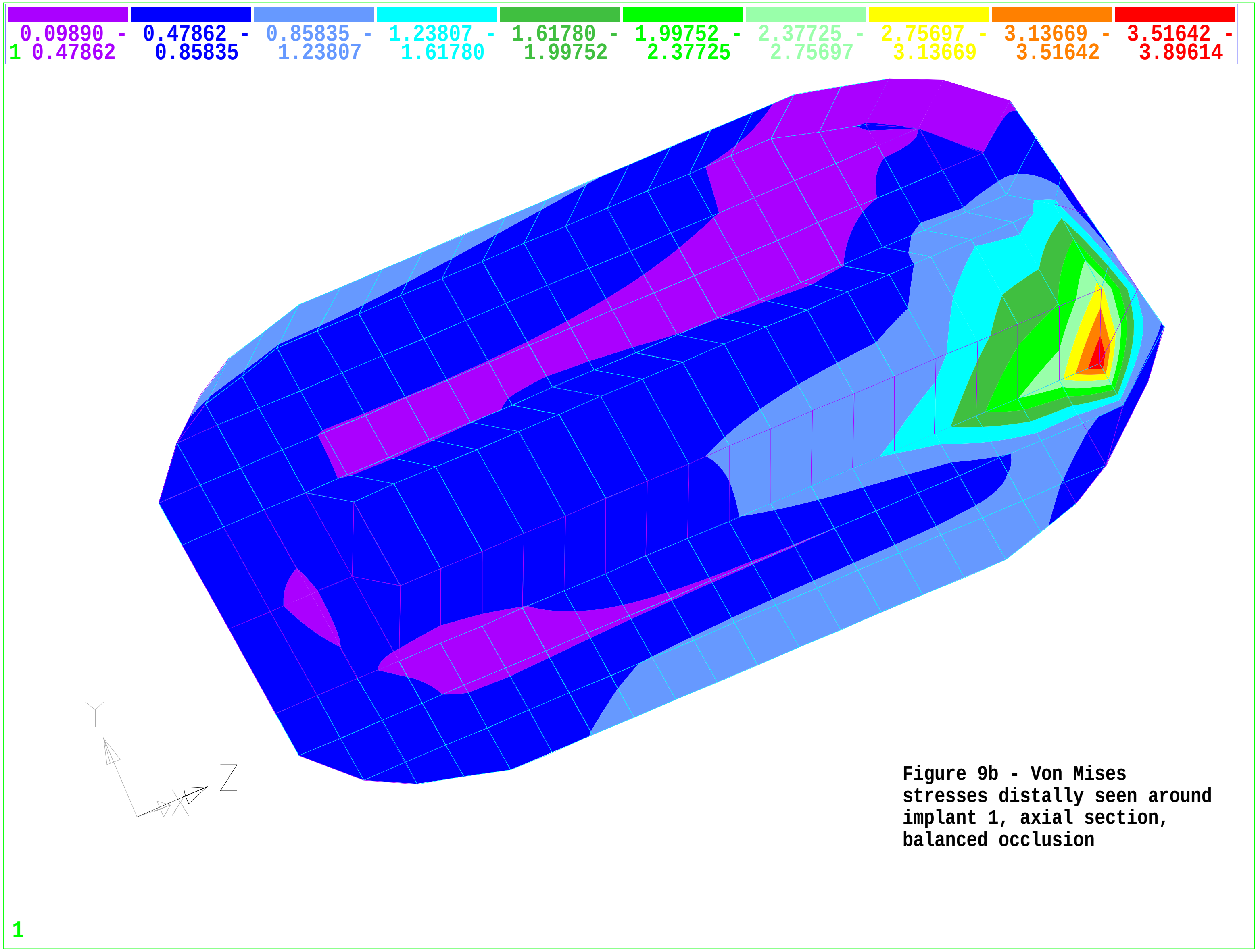

Figure 9b - Von Mises stresses distally seen around implant 1, axial section, balanced occlusion

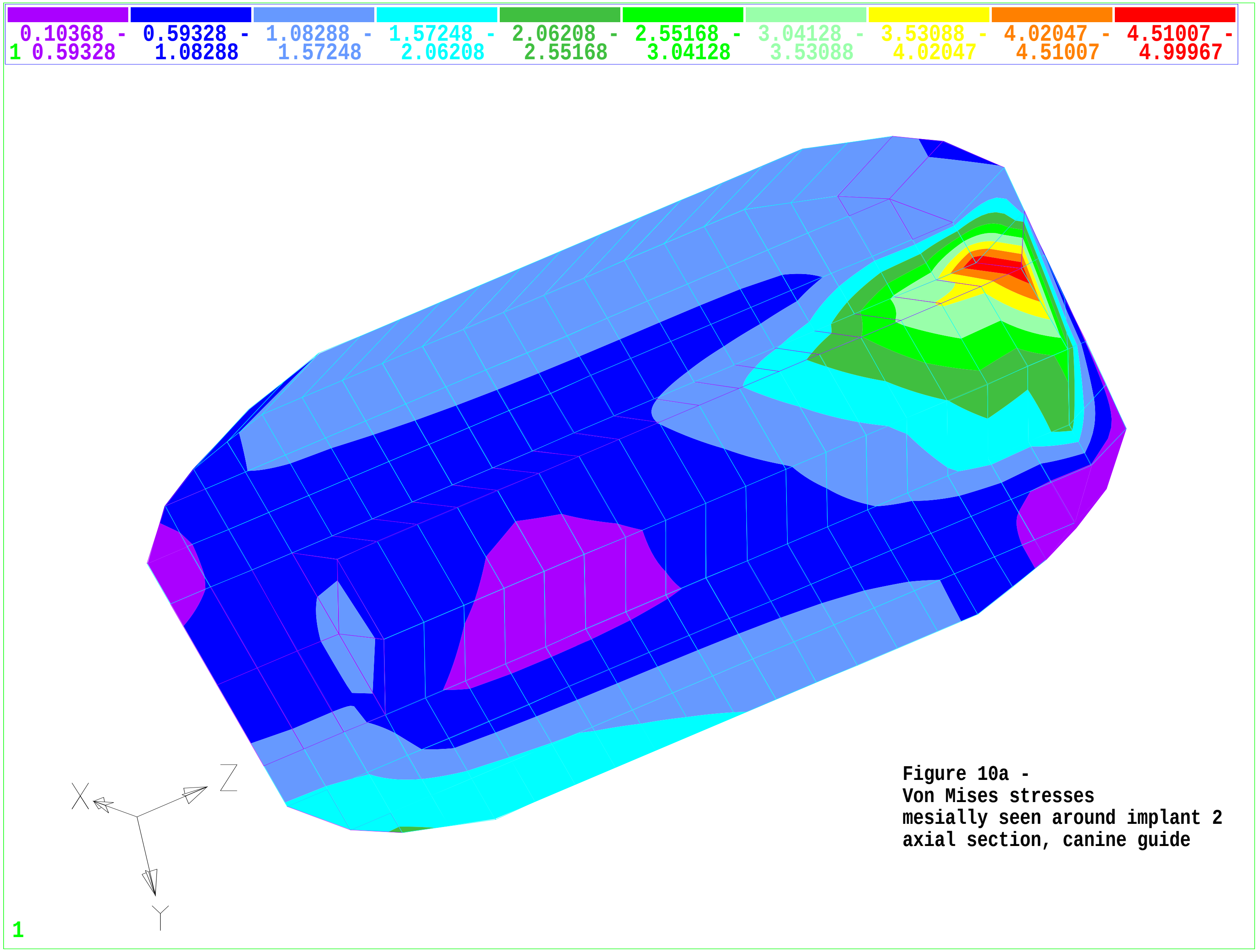

Figure 10a -
Von Mises stresses
mesially seen around implant 2
axial section, canine guide

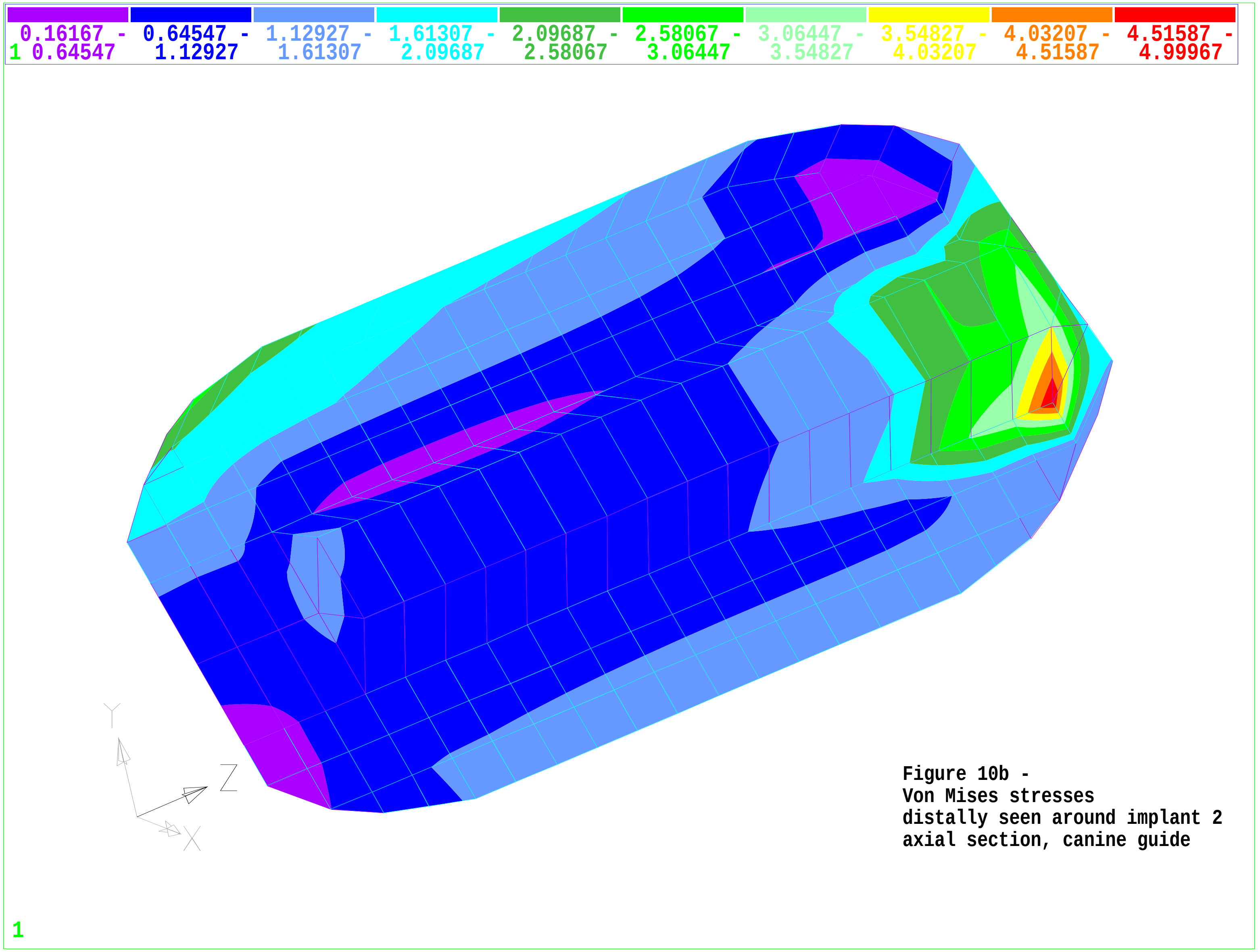

Figure 10b -
Von Mises stresses
distally seen around implant 2
axial section, canine guide

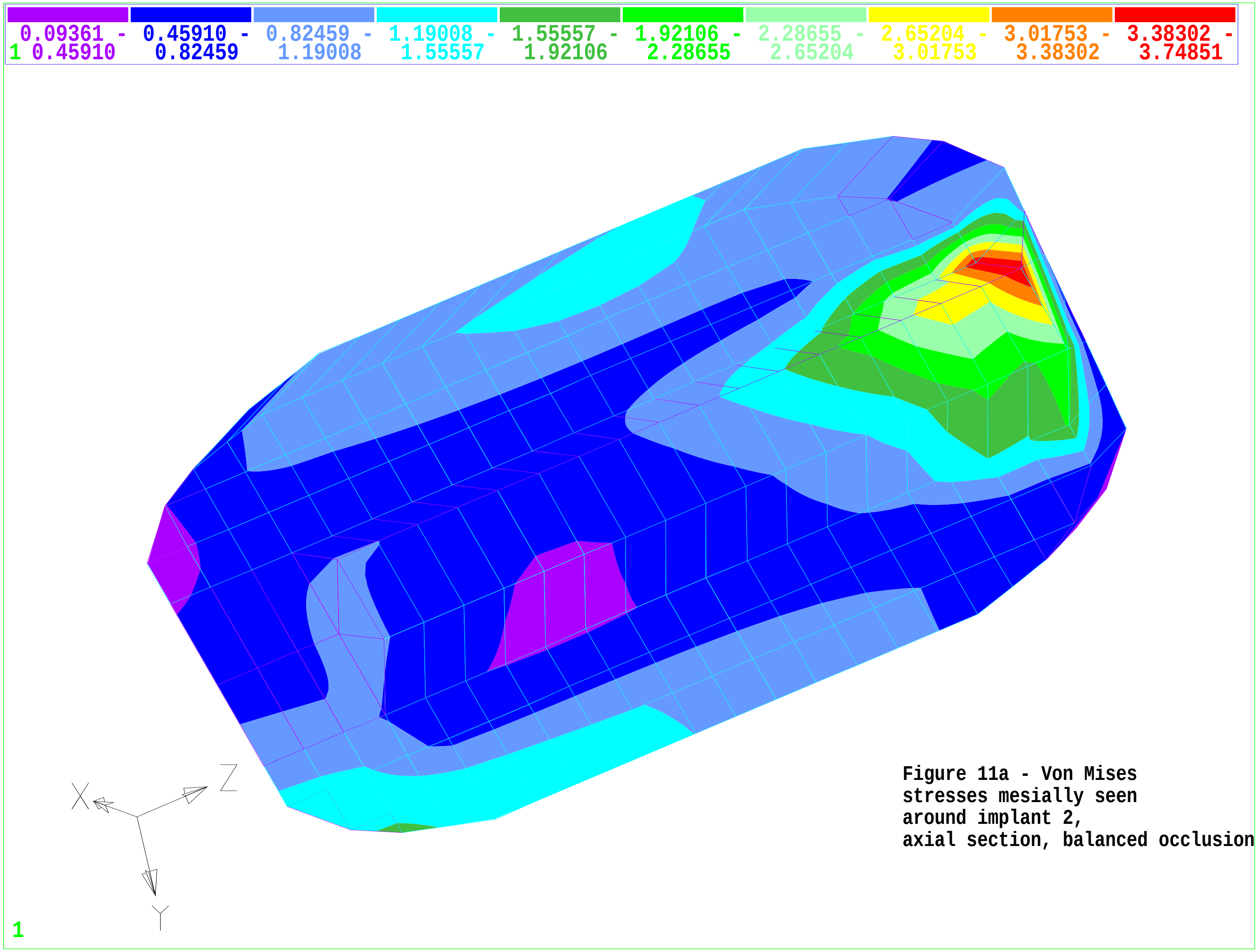

Figure 11a - Von Mises stresses mesially seen around implant 2, axial section, balanced occlusion

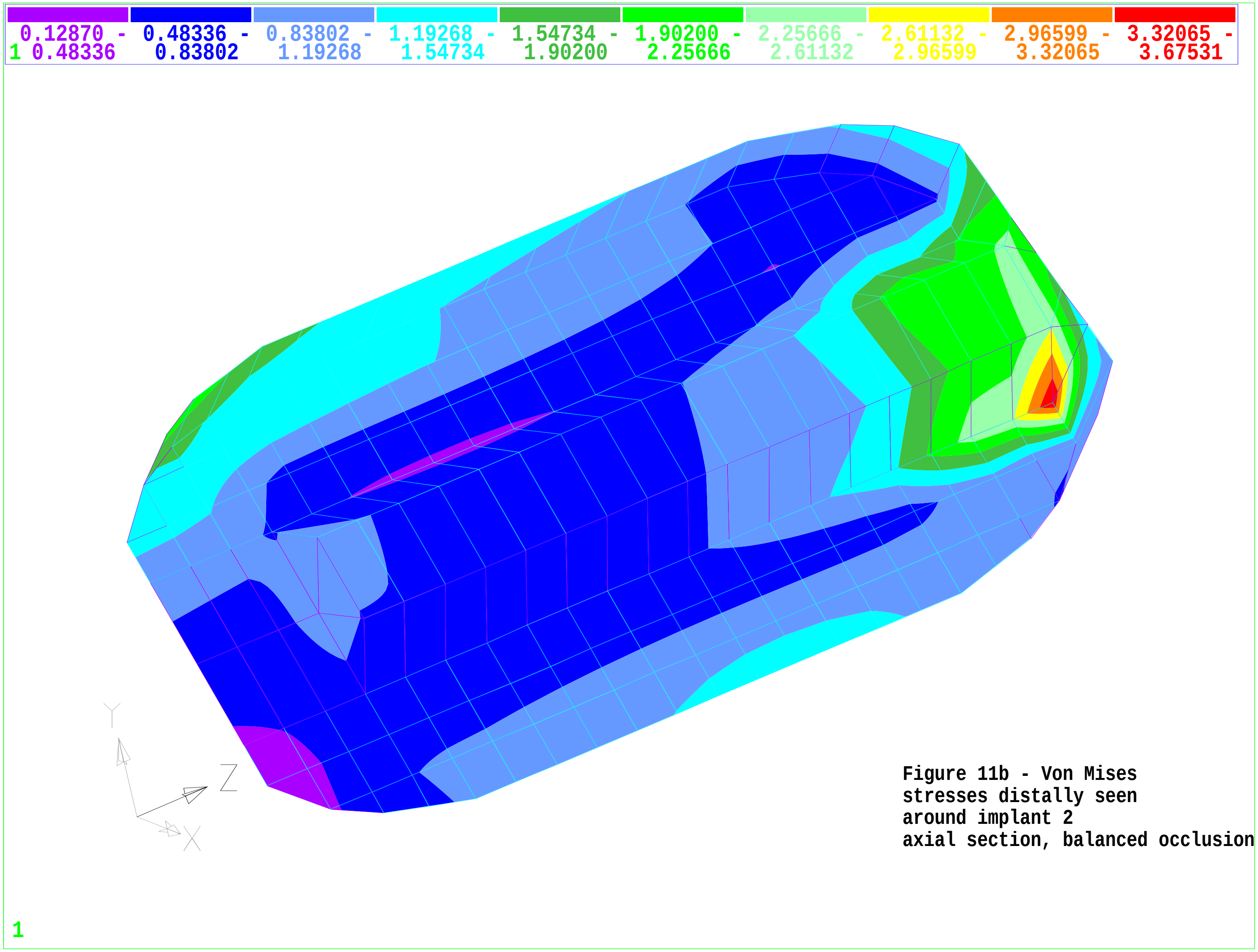

Figure 11b - Von Mises stresses distally seen around implant 2 axial section, balanced occlusion

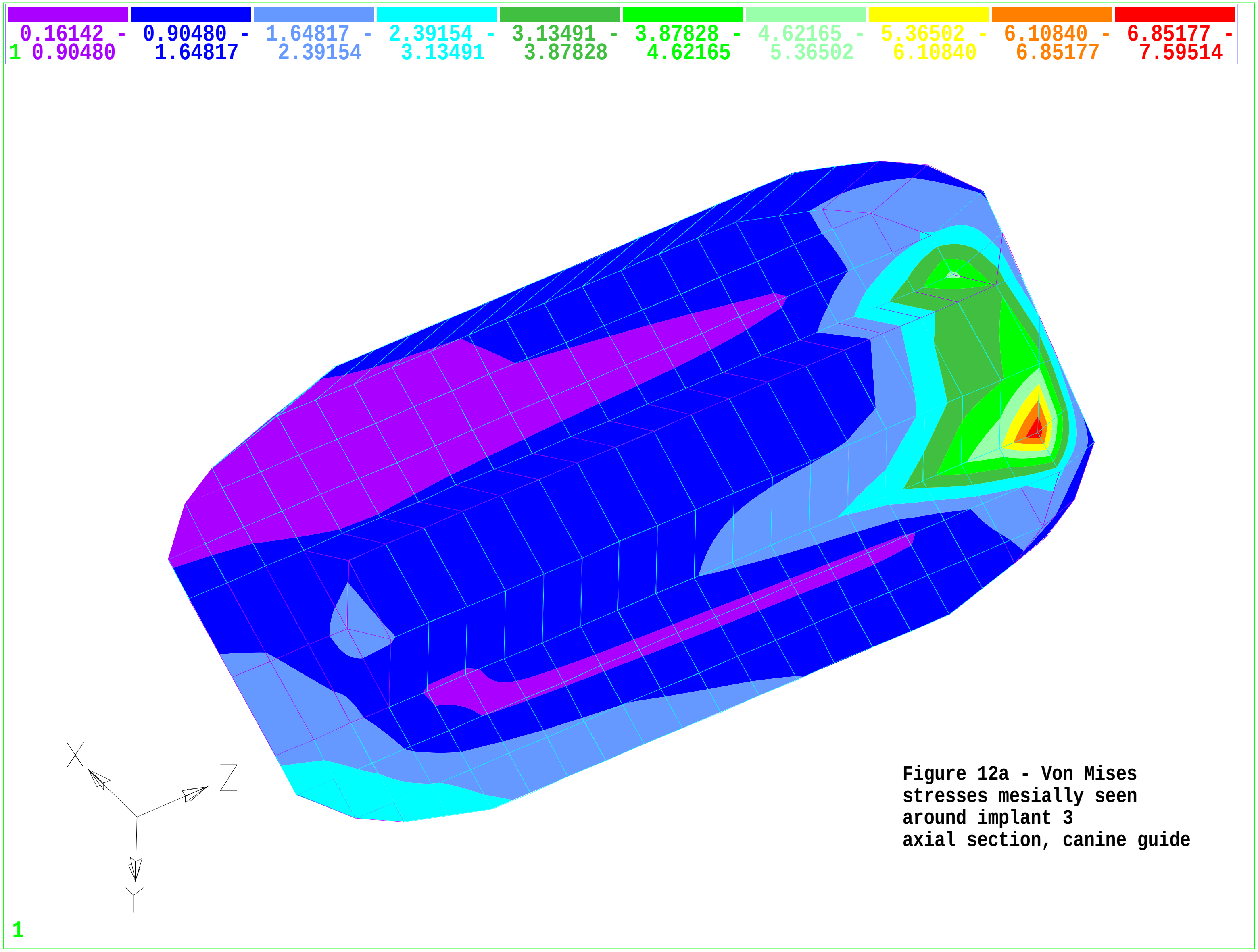

Figure 12a - Von Mises stresses mesially seen around implant 3 axial section, canine guide

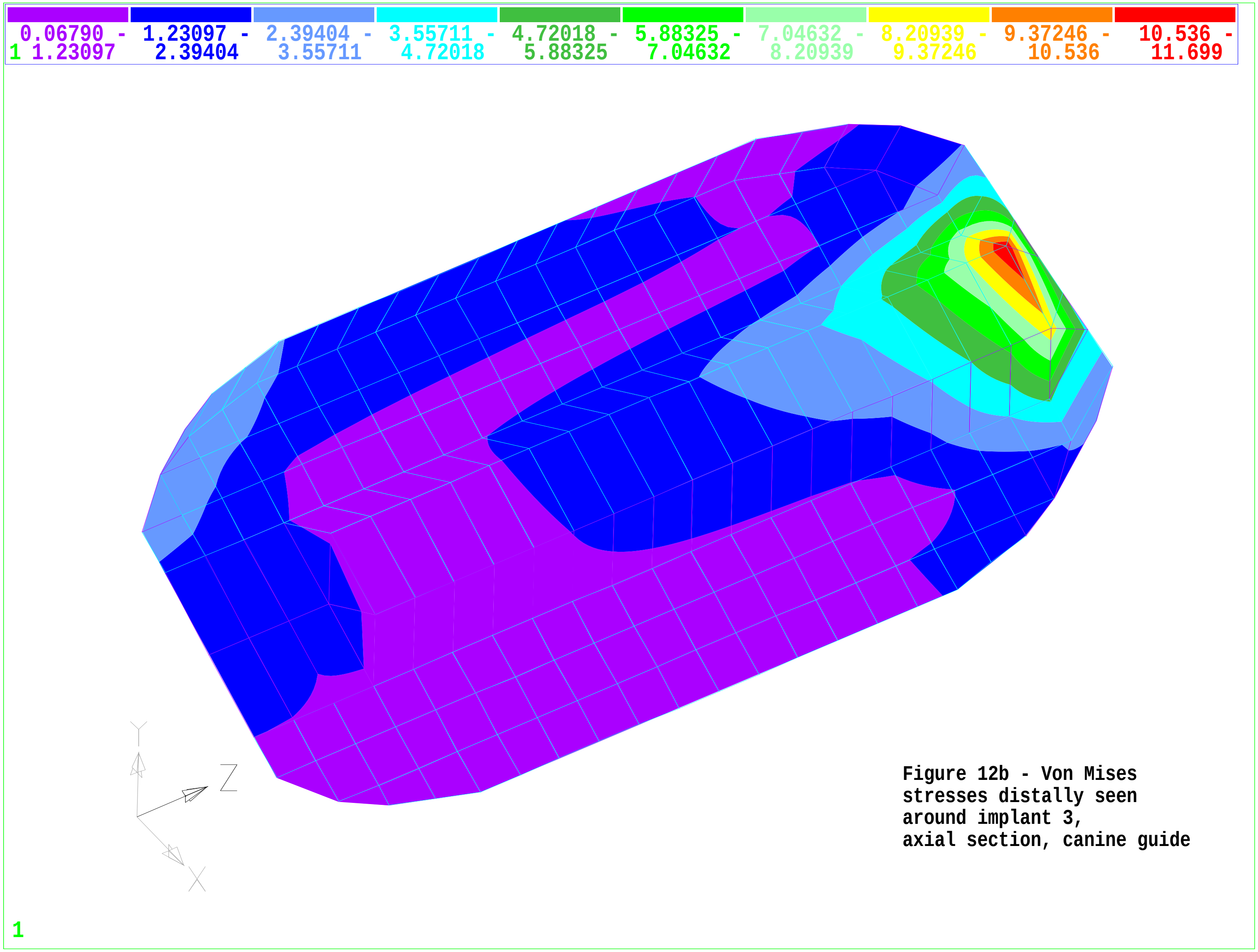

Figure 12b - Von Mises stresses distally seen around implant 3, axial section, canine guide

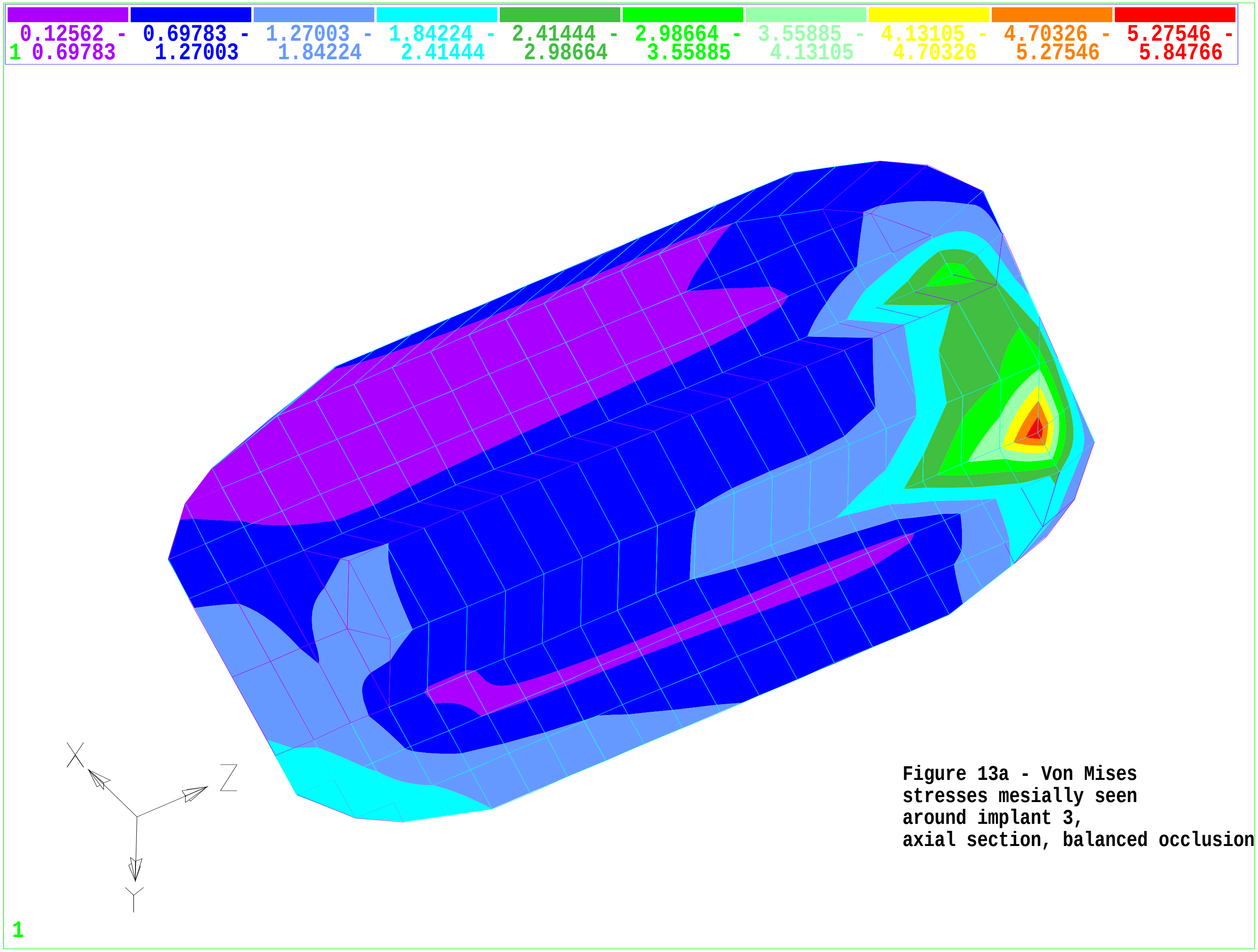

Figure 13a - Von Mises stresses mesially seen around implant 3, axial section, balanced occlusion

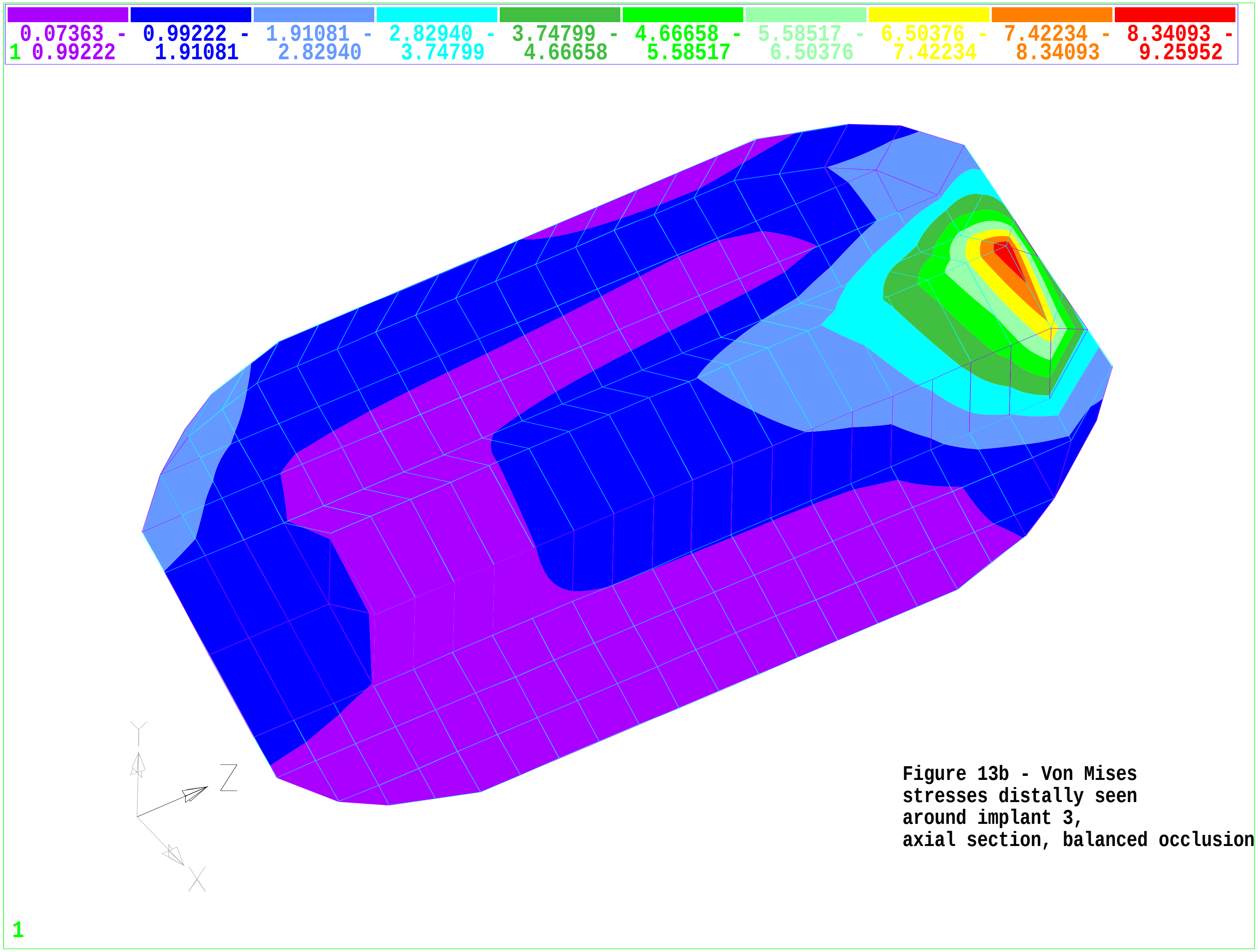

Figure 13b - Von Mises
stresses distally seen
around implant 3,
axial section, balanced occlusion

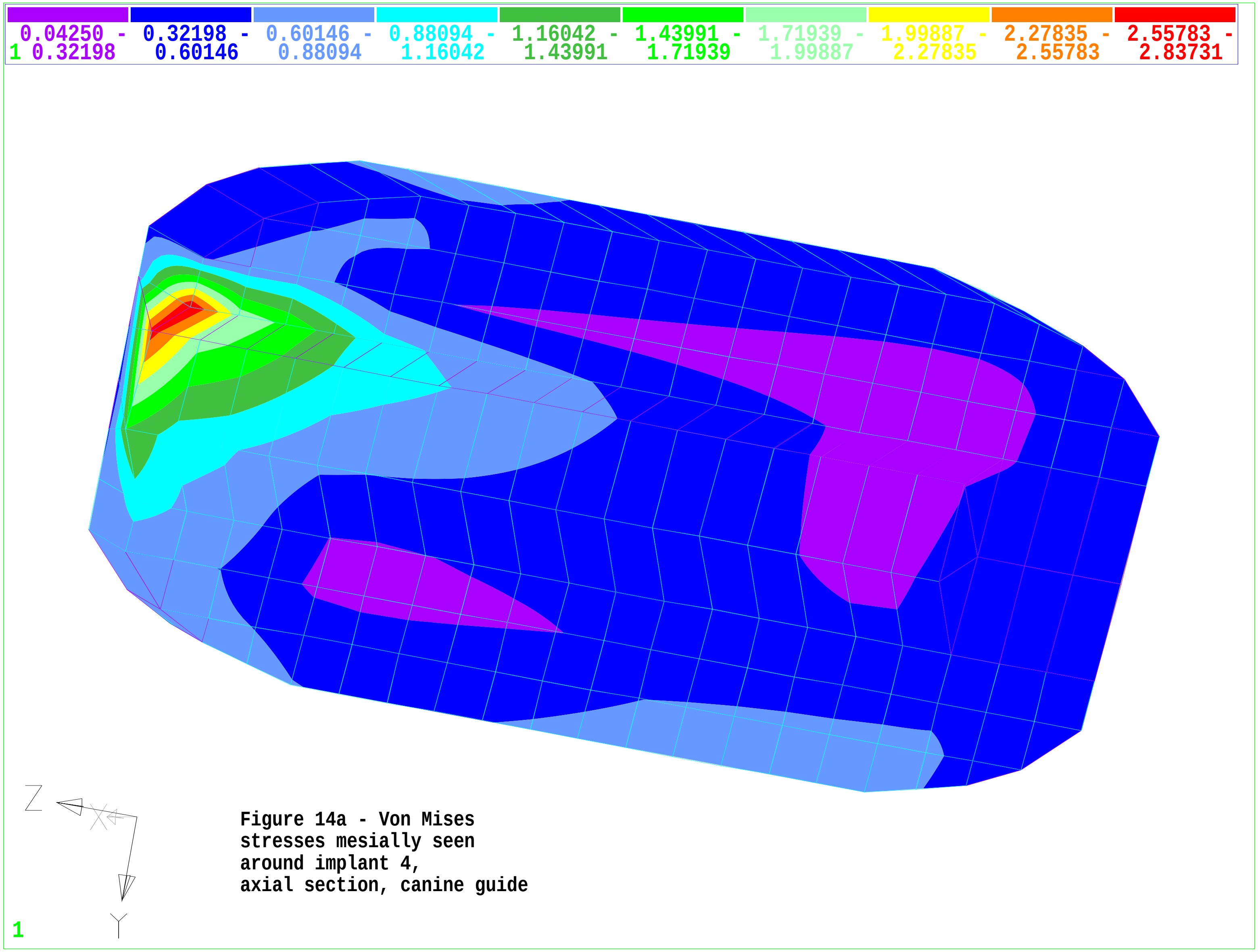

Figure 14a - Von Mises stresses mesially seen around implant 4, axial section, canine guide

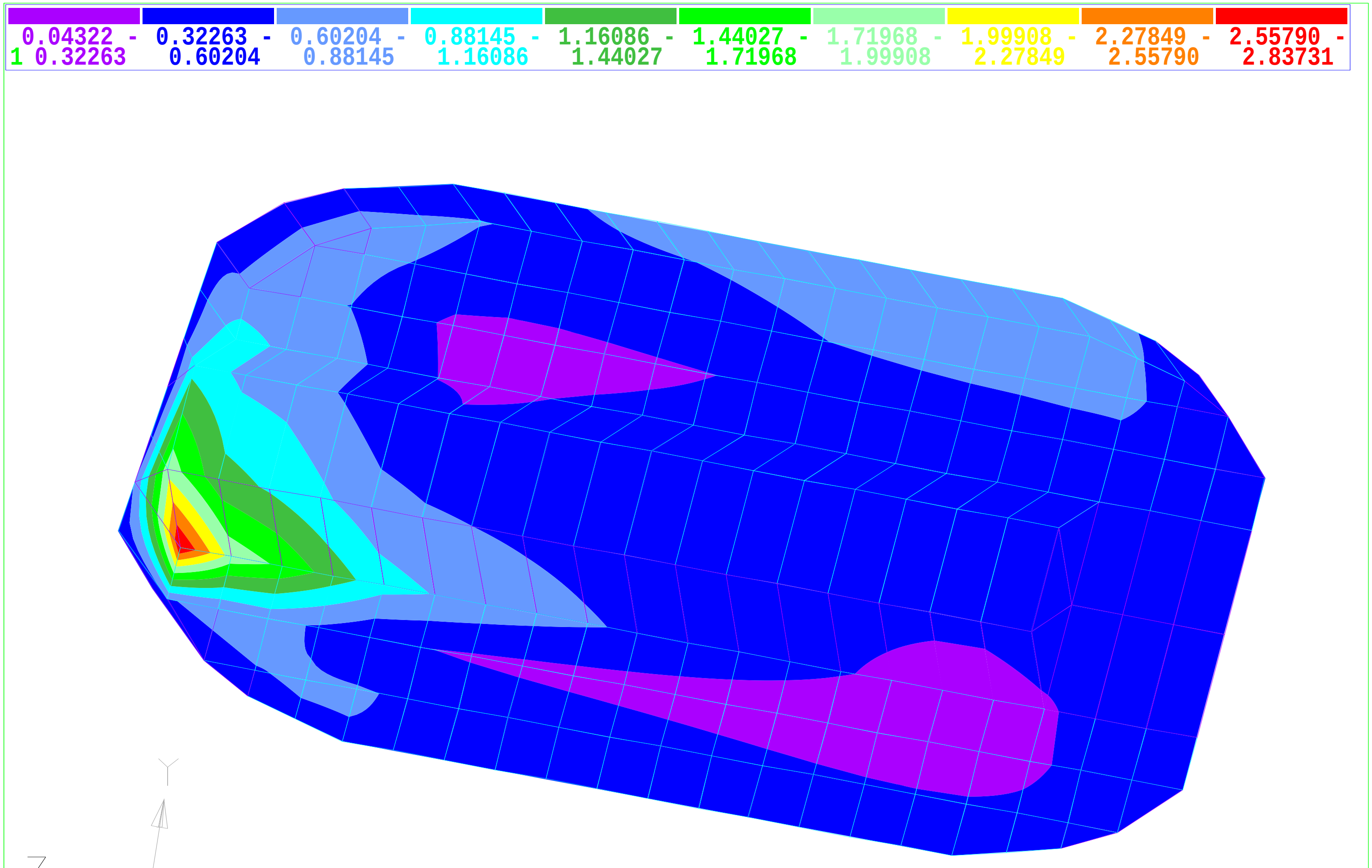

Figure 14b - Von Mises stresses distally seen around implant 4, axial section, canine guide

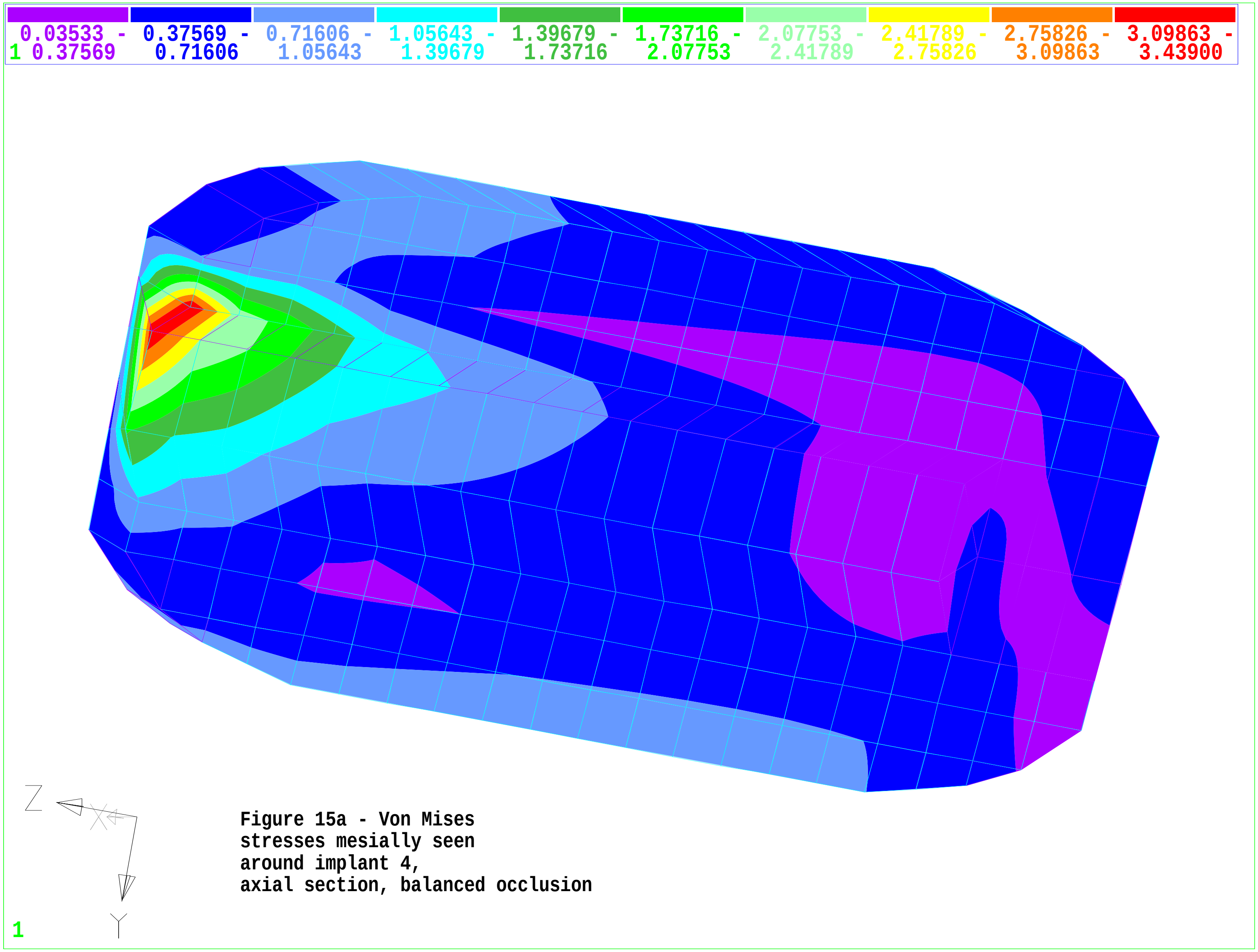

Figure 15a - Von Mises stresses mesially seen around implant 4, axial section, balanced occlusion

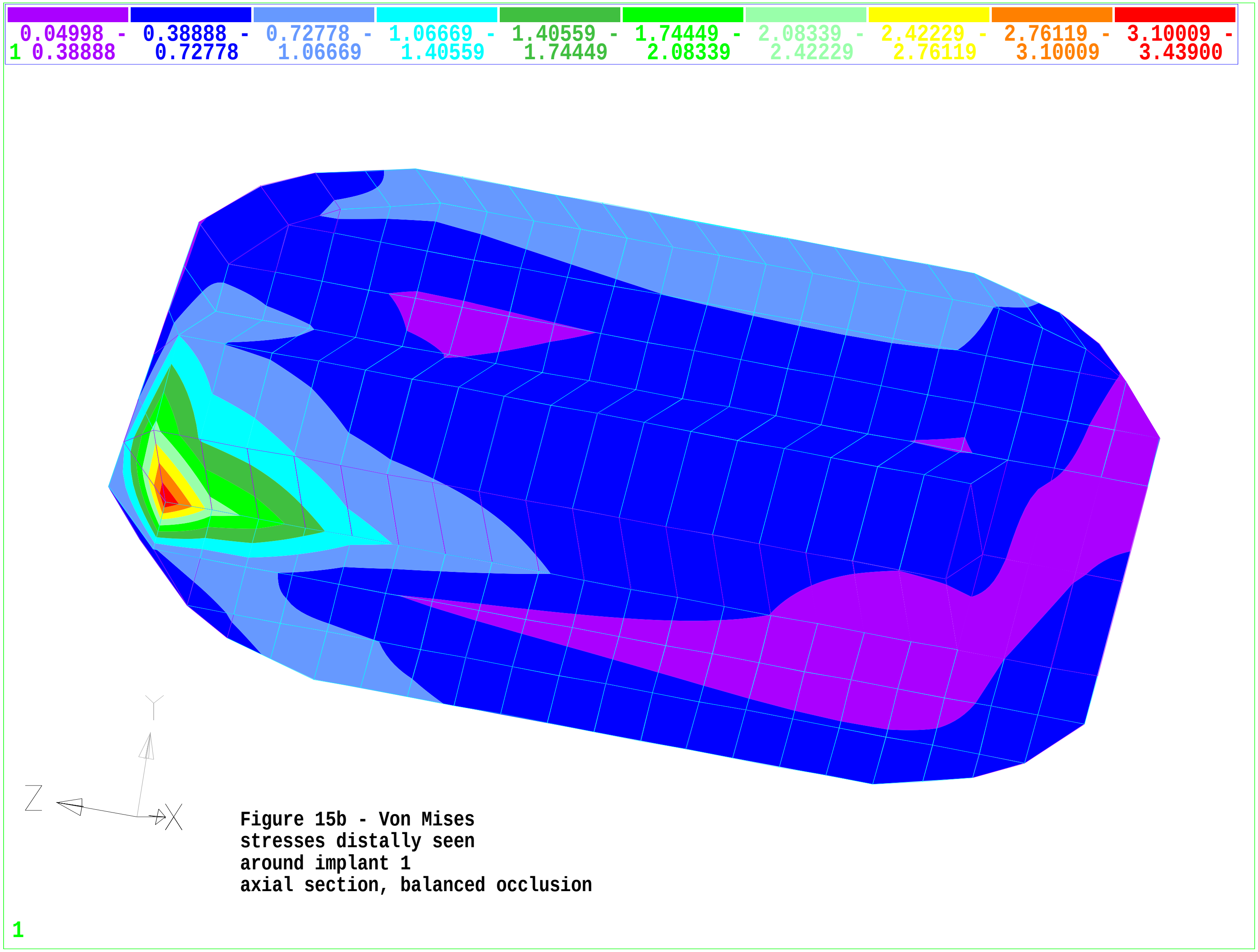

Figure 15b - Von Mises
stresses distally seen
around implant 1
axial section, balanced occlusion

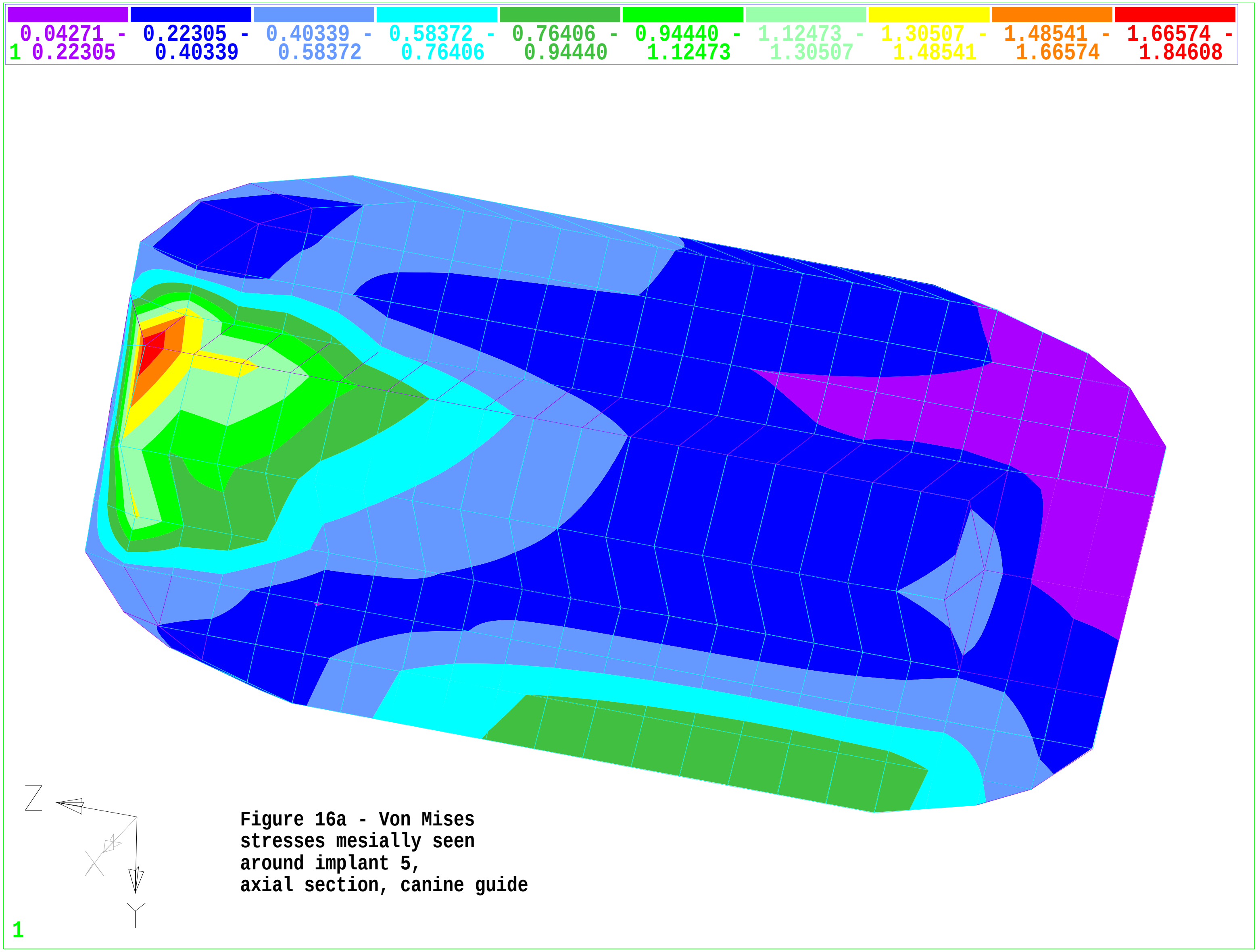

Figure 16a - Von Mises stresses mesially seen around implant 5, axial section, canine guide

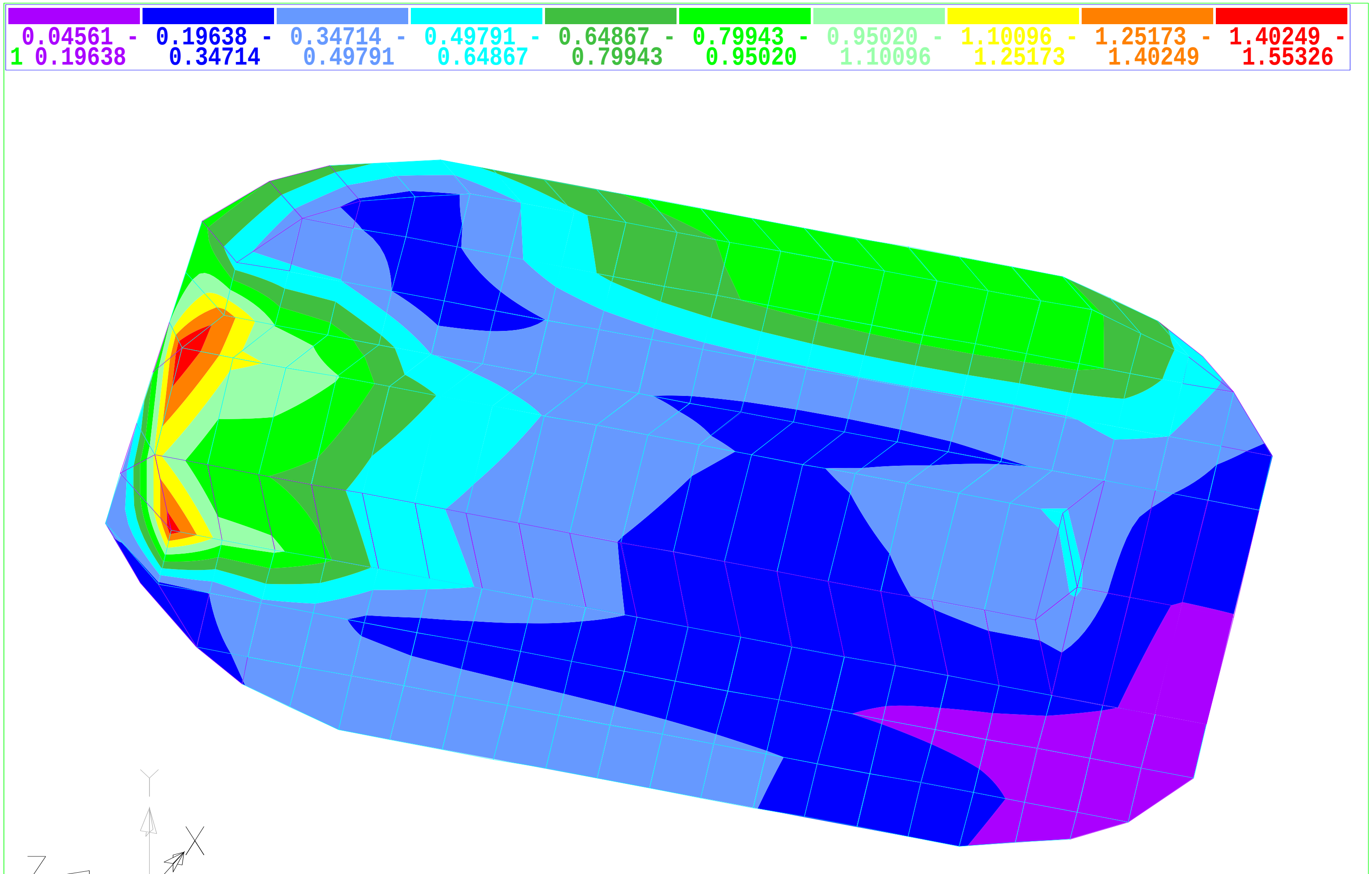

Figure 16b - Von Mises
stresses distally seen
around implant 5,
axial section, canine guide

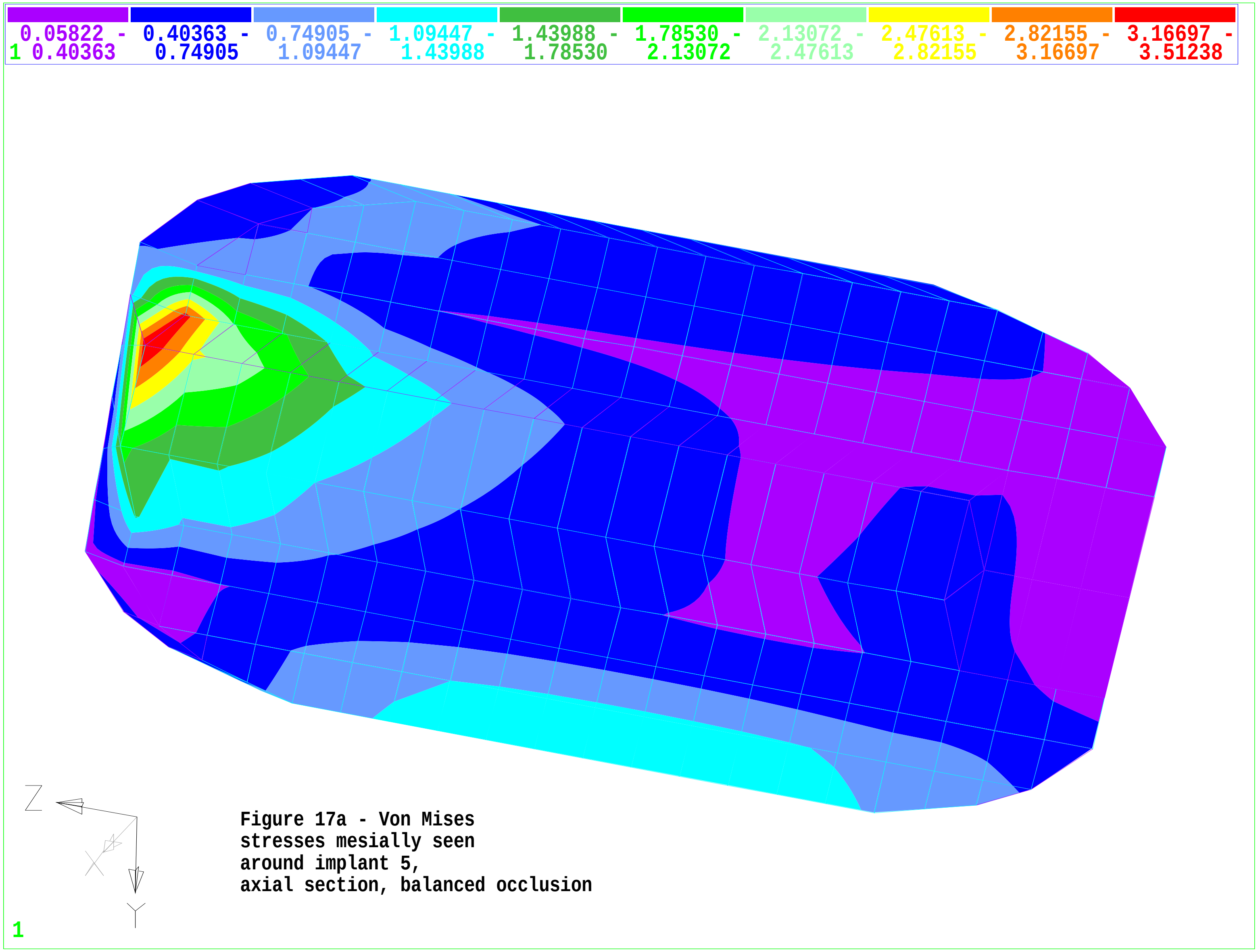

Figure 17a - Von Mises
stresses mesially seen
around implant 5,
axial section, balanced occlusion

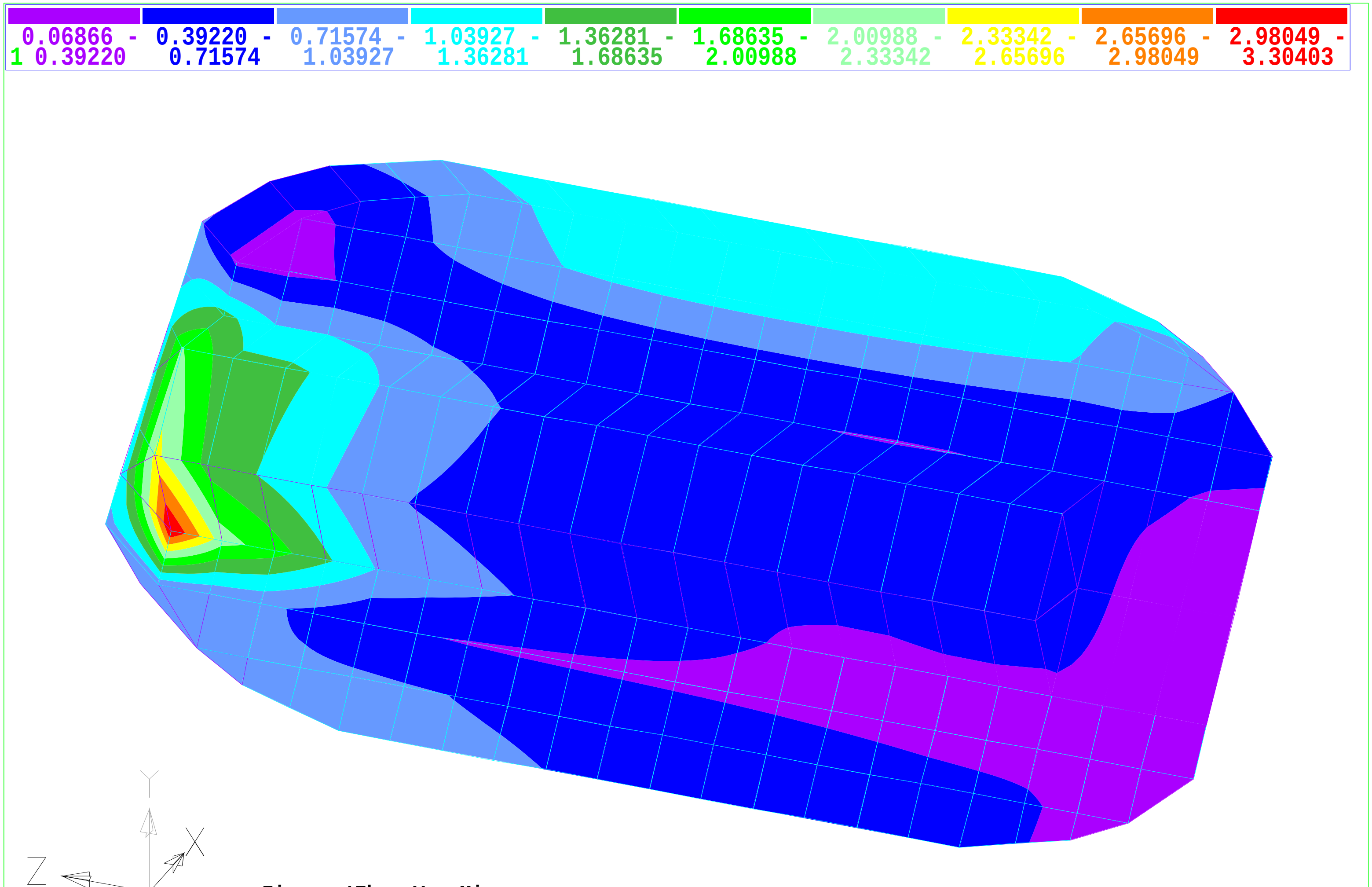

Figure 17b - Von Mises
stresses distally seen
around implant 5,
axial section, balanced occlusion

1

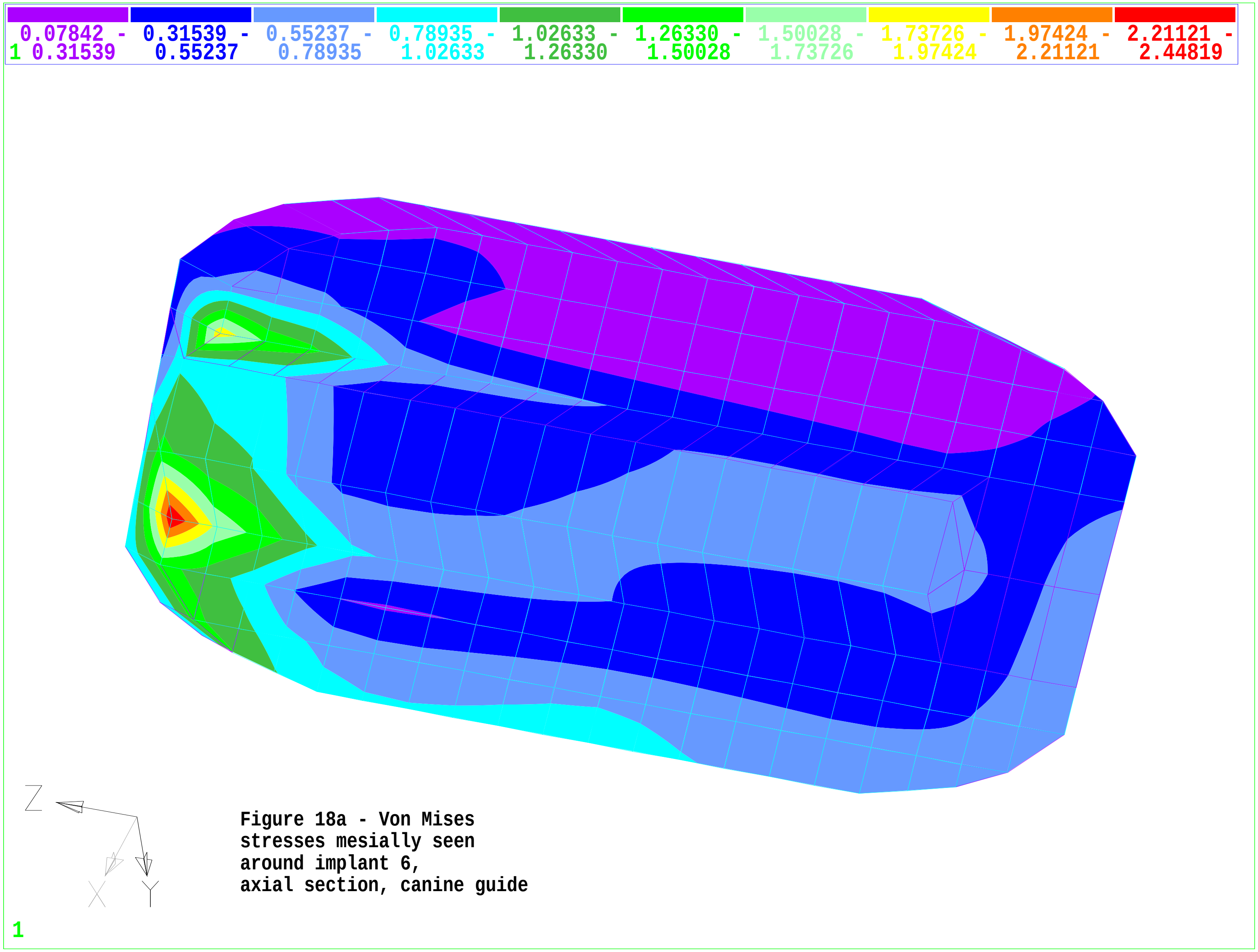

Figure 18a - Von Mises stresses mesially seen around implant 6, axial section, canine guide

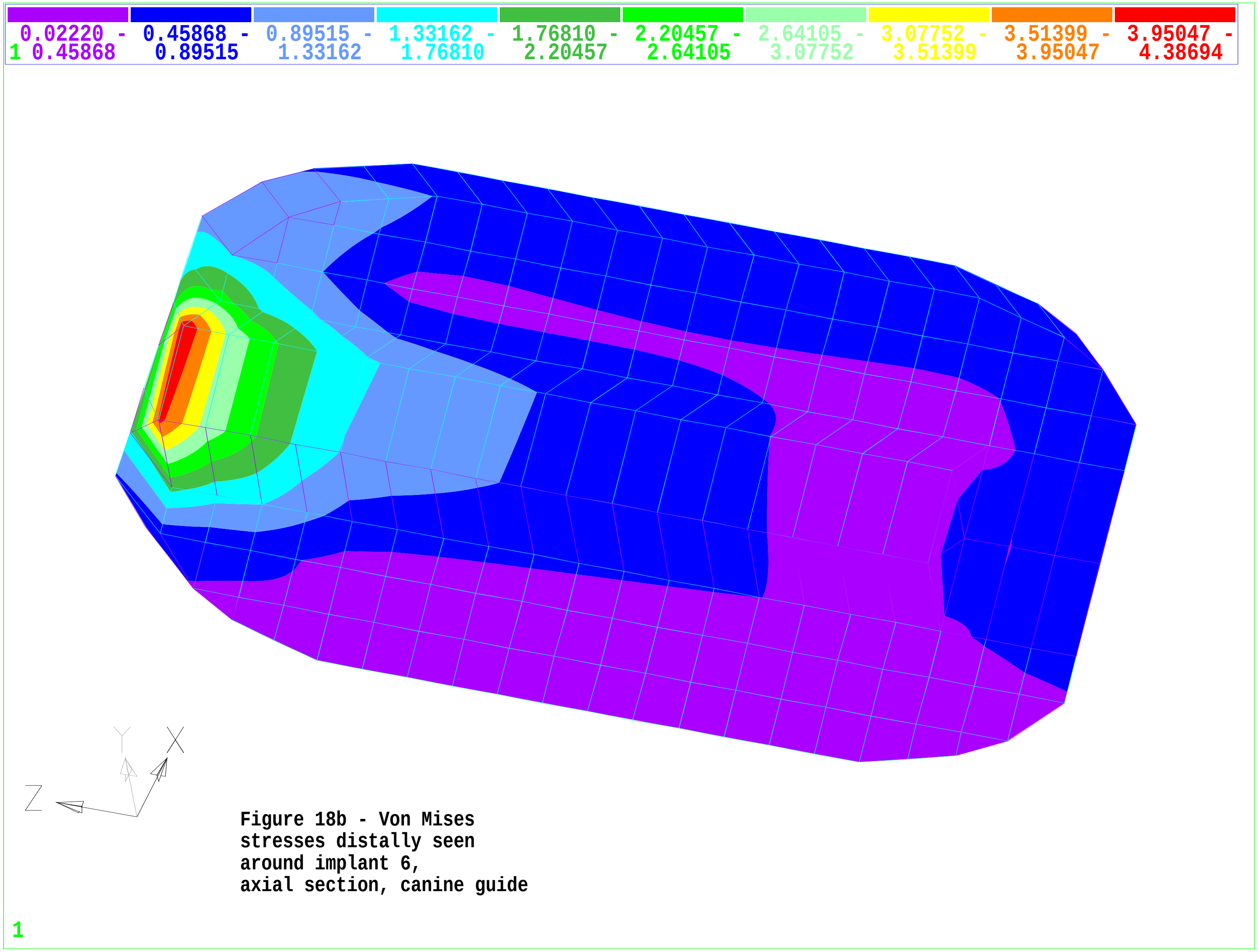

Figure 18b - Von Mises
stresses distally seen
around implant 6,
axial section, canine guide

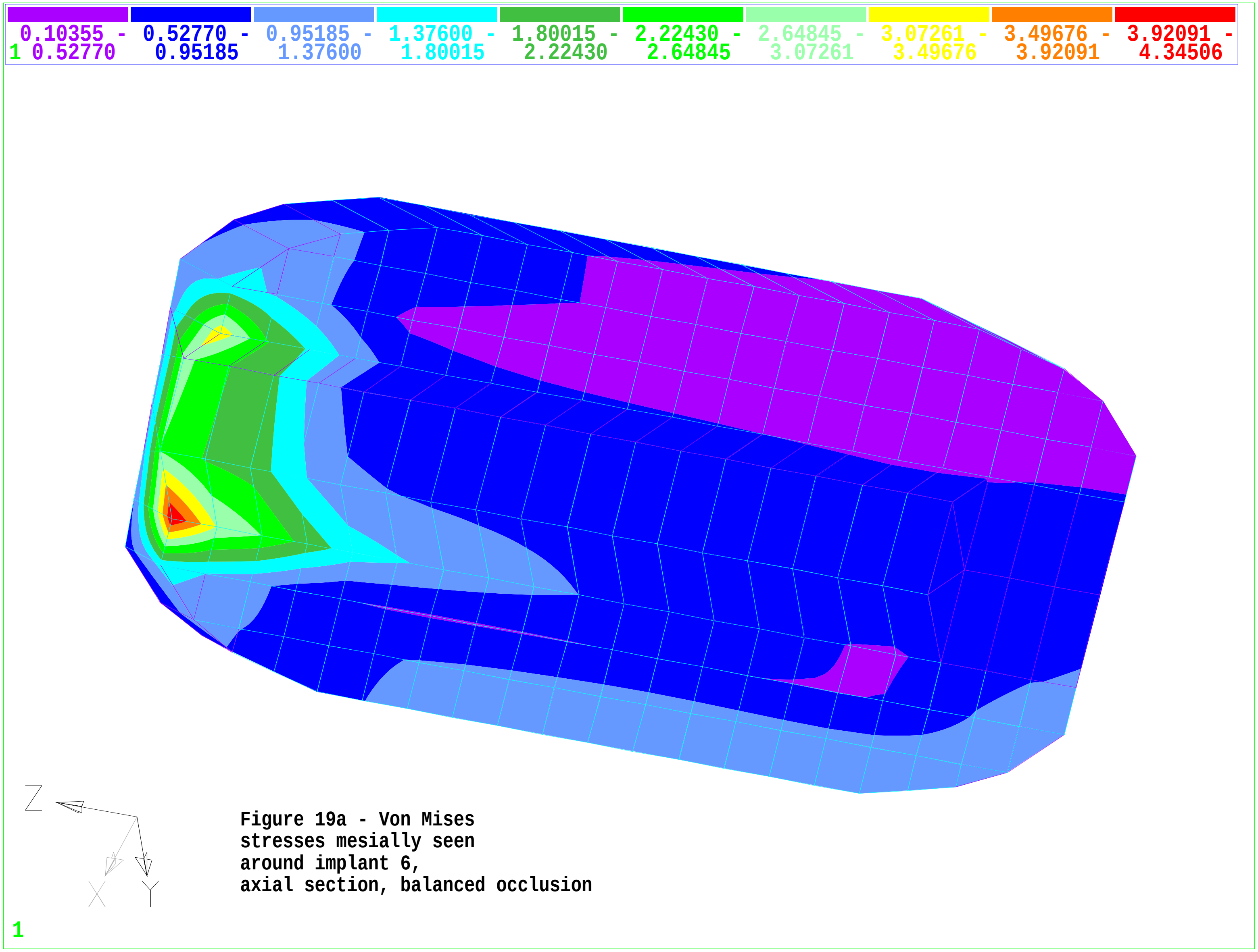

Figure 19a - Von Mises stresses mesially seen around implant 6, axial section, balanced occlusion

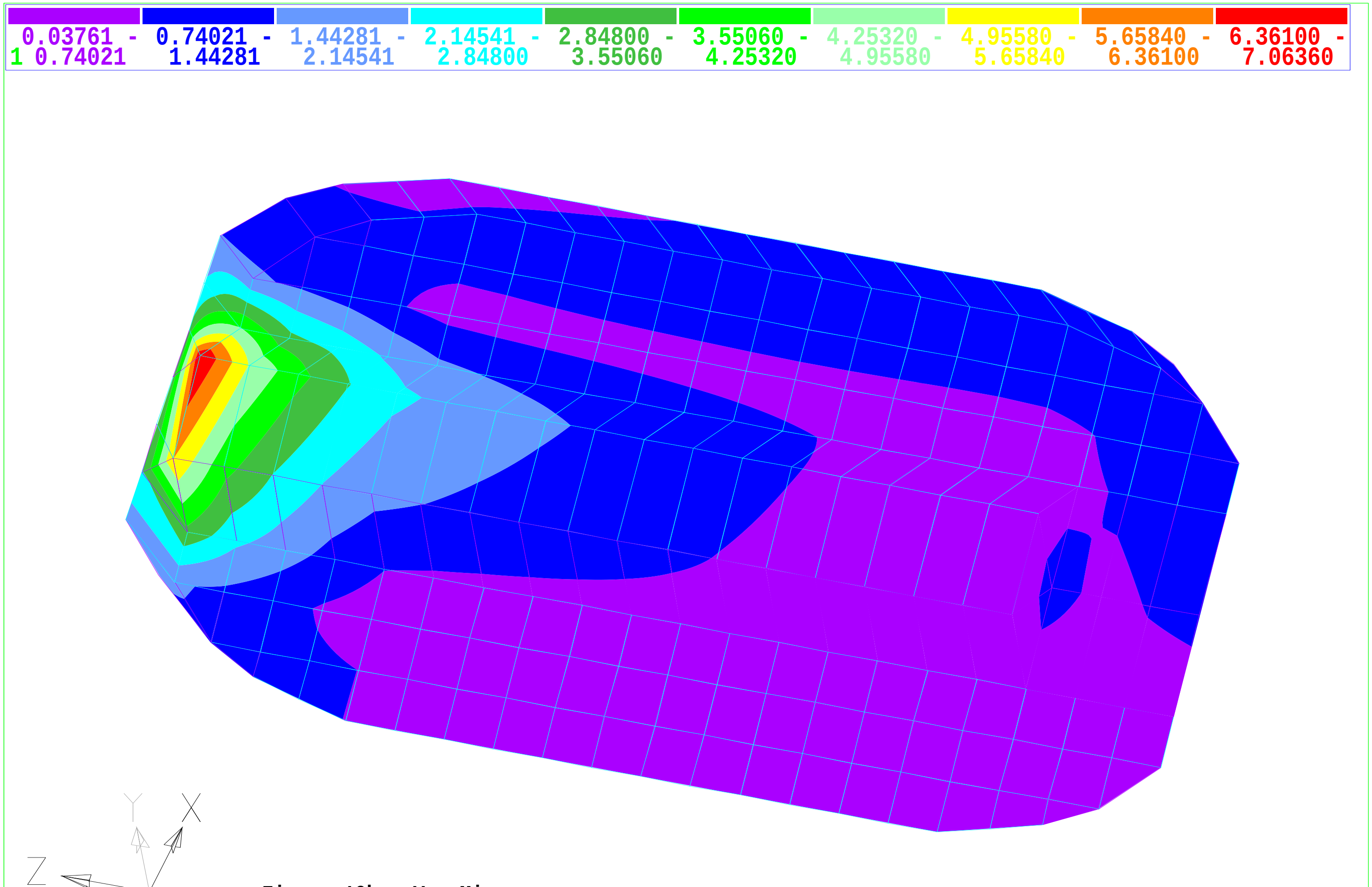

Figure 19b - Von Mises
stresses distally seen
around implant 6,
axial section, balanced occlusion

1