Evaluation of the Deformations on the Jaw Bone Due to a Band and Loop, Nance Appliance and Trans-Palatal Arch Space-Maintainers: A Three-Dimensional Finite Element Analysis

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Abstract

In cases where the loss of a primary tooth is unavoidable and the child is at a development stage it is important to preserve the remaining space by a space-maintainer. To evaluate the response and characteristic behavior of three different space-maintainers (band and loop, Nance appliance, and Trans-palatal arch) subjected to masticatory forces with 3D Finite Element Analysis.

It is a three dimensional digital solid model was prepared with a 'Solid Edge V20' software. The 'ANSYS Workbench' software was used in conjunction with 'Solid Edge V20' to simulate the behavior of the objects (teeth and the devices) under structural loading conditions. The forces and constraints are applied in appropriate magnitude and direction. The Von mises stresses, strains and deformation were derived for all three designs and jaw without device. Range of deformation for band and loop is 0 to 4.6292e-6, for Nance-appliance is 0 to 3.7612e-6 and for trans-palatal arch is 0 to 3.7666e-6. The deformation range for the model without the appliance is 0 to 4.9676e-6. The finite element analysis shows that, the Nance appliance shows the least deformation among all the three selected designs.

Keywords: Paediatric dentistry; Space maintainers; Finite element analysis; Pediatric appliances; Removable space maintainers; Fixed space maintainers

Introduction

Primary teeth play a critical role in the growth and development of a child. In addition to their role in esthetics, eating, speech, and to encourage normal function and resultant expected growth, the other main function of a primary tooth is to hold space for the permanent successor until it is ready to erupt [1]. A space-maintainer is an intra-oral appliance used to preserve arch length following the premature loss of primary teeth/tooth. This allows the permanent teeth to erupt unhindered into proper alignment and occlusion. Failure to maintain space results in Malocclusion like drifting / tipping of teeth, loss of arch length, midline shift, crowding of permanent teeth, impactions etc. Two main types of space maintainers are used to maintain the space in primary and mixed dentitions: fixed and removable appliances. Band and loop is the appliance of choice when a primary maxillary or mandibular first molar is prematurely lost. With the premature loss of a second primary molar, Nance or transpalatal (TPA) appliances can be used on the maxillary arch and the lower lingual holding arch (LLHA) for the mandibular arch [2]. The use of a removable space maintainer that is open on one end can be employed to guide the first permanent molar, maintaining the integrity of the mucous membrane and serving as a prosthetic appliance, preventing the complications and contraindications often caused by sub-gingival maintainers [3]. In those cases where the loss of a primary tooth cannot be avoided and the child is at a stage of development where their dentist feels that it is important that the resulting space must be preserved, a "space maintainer" can be placed.

There are numerous types of space maintainers. They can be classified broadly into four categories: removable or fixed and unilateral or bilateral. A removable space maintainer, of course, can be removed. Fixed space maintainers can be unilateral or bilateral. Unilateral space maintainers are fixed to one side of the mouth and bilateral space maintainers are fixed to both sides of the mouth. Consequently, we could have a maxillary removable bilateral space maintainer, or a

mandibular fixed unilateral right side space maintainer, and so forth. There are numerous variations on these basic themes. For example, some space maintainers are used for missing anterior teeth and some are used to preserve space for posterior un-erupted teeth.

Space closure occurs during the first 6 months after extraction. It is best to insert the appliance as soon as possible following the extraction. Erupting premolars usually require 4-5 months to move through 1 mm of bone as measured. Looking at the problems hitherto regarding preserving the arch length following the premature loss of teeth using different intra oral appliances, a problem is formulated. The complete project is carried out to evaluate the response and characteristic behaviour of different appliances subjected to masticatory forces. This analysis based project is expected to assist doctors and dentists in proper selection of appliance. Three most optimal designs are selected for this analysis namely Band and loop, Nance appliance and Trans-palatal arch. The objective of the study is three folds viz. 1) To model three different designs of space maintainers, 2) To carry out stress analysis of those designs, 3) To suggest optimal design for the success of space management following the premature loss of teeth.

Materials and Methods

The three dimensional digital solid model were prepared with a

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'Solid Edge' software (Solid Edge V20; Product Lifecycle Management Solution; Electronic Data System, Plano, TX, USA) [4]. The Solid Edge is 3-Dimensional CAD parametric feature solid modeling software [4]. The software combines direct modeling with dimension driven design (features and synchronously solving parametric) under the name 'Synchronous Technology' F. Parametric relationships can be applied directly to the solid features without depending on two dimensional sketch geometry, and common parametric relationships are applied automatically. An assembly is built from individual part documents using assembly features. Solid Edge supports large assemblies (over 100,000 parts). Solid Edge provides support for Finite Element Analysis (FEA) starting with Solid Edge V20 version released in 2007.

The solid models of the space maintainers were exported to ANSYS software (ANSYS ver. 14.0; SAS IP, Canonsburg, PA, USA) for stress analysis to perform a comparative study [4]. The destructive testing methodology can be reduced to some extent by using finite element method. ANSYS Workbench provides a framework for design exploration and optimization by enabling parametric modelling of geometric configurations, mesh controls, material properties, and operating conditions, leading to an automated simulation process. Modelling operations in ANSYS Design Modeller now directly accept geometry entities (like faces, edges and vertices), in addition to supporting named selections and sketches. In ANSYS 14.0, all features and tools are available for customization and exposure via toolbars to help users customize the interface with frequently used features, along with tools for easy and direct access [4]. The outcome of the research suggests that performing stress analysis helps in deciding an optimal design of an appliance for space management.

Modelling using solid edge

Model for device 1 (Band and Loop): The model for the device was prepared by taking the models of jaw and the teeth as a reference (Figure 1). The thickness of the "band" is given as 0.2 mm, so a square of 10.4×10.4 mm with fillets of radius 2.2 mm on all sides was protruded around the existing tooth for 5 mm i.e. for the part of tooth above the jaw. A cutout of the shape of the tooth i.e. 10×10 mm with fillets of 2 mm on all sides was made on the protruded face till 5 mm. To model the 'loop', a circle of diameter 1 mm was protruded from the face of the band facing the gap for 6.8 mm on both the sides symmetrically. Then the two straight parts of the loop were joined by sweep protrusion till an angle of 90° and a small straight protruded part till the geometry is complete. First the teeth were placed into the jaw cutouts by flash fitting

Figure 1: Tooth cutout profile and positioning for Band and loop space-maintainer.

aligning of three mutually perpendicular surfaces together. Then the inner faces of the band cutout is aligned with one of the teeth and then finally lower surface of the band was flash fitted with the upper surface of the jaw to get the complete assembly as shown in Figure 2.

The solid edge model of the jaw for device 2 and device 3: As the device 2 is a biaxial device, it needs the support of both the sides of the jaw. So the complete jaw was modelled. First, a protrusion of the following geometry was made till the height of 20 mm. Then a cutout of the following geometry as shown in Figure 3 was made on the top face till a depth of 15 mm. To place the teeth, box of 10 mm×10 mm with fillets of radius 2 mm on all the sides, cut-outs were made on the jaw symmetrically on both the sides till a depth of 10 mm. By taking the jaw as a reference, protrusions were made from the existing cutouts of 10×10 with fillet of 2 mm on all sides, till a height of 15 mm to form teeth like structures. Thus, the complete model of the jaw and teeth was obtained. The 3-D model of jaw was thus created without device and later two devices, namely Nance appliance and Transpalatal appliance were fitted.

The solid edge model of the jaw with the device 2: The models of jaws and teeth were taken as a reference to model the device. The thickness of the band walls is given as 0.2 mm. Protrusion was made, by taking the top face of the tooth as a reference, of 10.4×10.4 mm with fillets of radius of 2.2 mm on the sides, till a height of 5 mm. Cutouts

Figure 2: 3-D view of the assembly for band and loop space-maintainer.

Figure 3: Tooth cutout profile and positioning for Nance appliance and Trans-palatal arch space-maintainer.

were made on the protruded face of the shape and size of the tooth i.e. 10×10 mm with fillets of 2 mm on the sides, till a height of 5 mm. This was repeated for the 2nd tooth to form bands on both the teeth. Then a wire of diameter 1 mm was created in the geometry of the device with the help of protrusion and sweep protrusion commands. Thus the 3-D model of the Device 2 is obtained. The parts are assembled together by series of operations to get the following assembly with Device 2 as shown in Figure 4.

The solid edge model of the jaw with the device 3: The models of jaws and teeth were taken as a reference to model the device. The thickness of the band walls is given as 0.2 mm. Protrusion was made, by taking the top face of the tooth as a reference, of 10.4×10.4 mm with fillets of radius of 2.2 mm on the sides, till a height of 5 mm. Cutouts were made on the protruded face of the shape and size of the tooth i.e. 10×10 mm with fillets of 2 mm on the sides, till a height of 5 mm. This was repeated for the 2nd tooth to form bands on both the teeth. Then a wire of diameter 1 mm was made into the geometry of the device with the help of protrusion and sweep protrusion commands. The parts are assembled together by series of operations to get the following assembly with Device 3 (Figure 5).

Finite element analysis

The 'ANSYS Workbench' software is used in conjunction with Solid Edge to simulate the behavior of the objects (teeth and the devices)

Figure 4: 3-D view of the assembly for Nance appliance space-maintainer.

Figure 5: 3-D view of the assembly for Trans-palatal space-maintainer.

under structural loading conditions. ANSYS automated FEA (finite element analysis) technologies are used to generate results. The analysis is carried out on simplified models of jaw containing the teeth and the devices. Linear analysis of the simplified models of jaw containing the tooth without device and with device is carried out. The assemblies that were modelled in the software Solid Edge V20 were saved using the IGES format. Now the geometries were ready to be imported into the ANSYS Workbench software.

Steps required for pre-processing

Assigning materials: The entire model is an assembly of 3 to 4 parts. Each part is named in ANSYS Workbench and material properties for each part are assigned as per the Table 1.

Meshing: The models were meshed using the "Generate Mesh" function. The mesh generated was a free mesh using the SOLID92 element types (Figures 6A-6C). SOLID92 element (3-D 10-Node Tetrahedral Structural Solid) has quadratic displacement behavior and is well suited to model irregular meshes. The element is defined by 10 nodes having three degrees of freedom at each node: translations in x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

Applying forces and constraints: The forces and constraints are applied using the settings in the static structural option in the workbench. To apply a particular force, magnitude and direction of the force is specified and geometry is selected on which the force is applied. Similarly for applying constraints, type of constraint is chosen, then the geometry on which the constraint to be applied is selected.

a) Forces: For this study, the masticatory forces on the teeth were applied on the complete surface of the tooth, vertically downwards, with a magnitude of 1000 N.

b) Constraints: The complete jaw is considered to be fixed including the inner areas of the tooth cavities. Only one side of the tooth cavity is not fixed and that is the one towards the gap. So whatever might be the loading, the tooth is free to move in only one direction. The entire summary for the 4 models in workbench is listed in Table 2. It also shows the type of elements used for meshing. The Figures 6A-6C shows the meshed model for each assembly.

Results

For the masticatory loading (chewing condition, FE analysis is carried out as discussed in the previous section. The solid models are imported from Solid Edge software to ANSYS Workbench and material properties are assigned as per the Table 1. Load of 1000 N is applied. They are solved to get the final solution. The contour plot of 'von mises stresses' and 'strain' were separately obtained for all the three appliance models as well as the jaw model without the device. The final deformation is plotted with the result of 'von mises stresses' and 'strain' calculations and shown in Figures 7A-7C for the band and loop, Nance appliance and Trans-palatal arch respectively. The total nodes, elements and element types for each model with or without devices are indicated in Table 2.

S. No.	Material	Young's modulus (GPa)	Poisson's ratio
1.	TOOTH	19.0	0.3
2.	BONE	15	0.3
3.	STAINLESS STEEL	193	0.31

Table 1: Materials Properties.

Figure 6: (A): Meshed model of Band and loop space-maintainer; (B): Meshed model of Nance appliance space-maintainer; (C): Meshed model of Nance appliance space-maintainer.

Figure 7: (A): Finite element analysis of the band and loop space-maintainer; (B): Finite element analysis of the Nance-appliance space-maintainer; (C): Finite element analysis of the Trans-palatal arch space-maintainer.

The von mises stresses, strains and deformation were derived for all three designs and jaw without device as shown in Table 3. From the above results, ‘Nance appliance’ shows the least deformation among all the three selected designs. So this model can be chosen as the optimum model.

Discussion

The space maintainers are useful in preventing undesirable tooth movement following the premature loss of a primary tooth, maintain space, prevent over eruption of opposing teeth, improve esthetics, assist in speech (anterior segments), aid in control of deleterious oral habits. The majority of bilateral space maintainers (72%) lasted their anticipated lifetimes [5]. Fathian et al. studied survival times and problems encountered with laboratory made space maintainers placed

over 7 years by one paediatric dentist. A total of 63% of all space maintainers lasted their anticipated lifetimes or were still in use [6]. The aim of this study was to evaluate the median survival time of fixed and removable space maintainers related to age groups, gender, and their distribution in upper and lower dental arches. The overall median survival time of the appliances was 6.51 months. Median survival time of space maintainers was 7.17 months for maxilla and 6.69 months in the mandible. Median survival time was 5.25 months for space maintainers fabricated in both arches [7]. The results suggested that the space maintainers remain in effect in a considerable period of time in mouth in actively growing jaw bones. The eruption time of the permanent teeth also add more active changes in the maxilla and mandible. Hence the study of stresses developed by these appliances becomes very much critical. Unfortunately there is a scanty data available in previous literature regarding the behaviour of these appliances with their stress pattern on the developing jaw bone.

Following the 3D finite element analysis of the three appliances studied, the Nance-appliance shows the lesser deformation than band and loop and trans-palatal arch. However, Lin et al. [8] investigated dental-arch space problems arising as a result of premature loss of a

Appliance	Material	Bodyname	Nodes	Elements	Element type
Without device	Enamel	Tooth1	60414	13890	SOLID92
	Enamel	Tooth2	62535	14340	SOLID92
	Bone	Jaw	114821	66158	SOLID92
	Total		237770	94388	
For Band and Loop	Enamel	Tooth1	60137	13800	SOLID92
	Enamel	Tooth1	60875	13980	SOLID92
	Bone	Jaw	43026	24135	SOLID92
	Stainless steel	Device1	5967	2737	SOLID92
	Total		170005	54652	
For Nance appliance	Material	Body name	NODES	ELEMENTS	ELEMENT TYPE
	Enamel	Tooth1	60414	13890	SOLID92
	Enamel	Tooth2	62535	14340	SOLID92
	Bone	Jaw	114821	66158	SOLID92
	Stainless steel	Device	13182	5883	SOLID92
	Total		250952	100271	
For Trans-palatal arch	Material	Body name	NODES	ELEMENTS	ELEMENT TYPE
	Enamel	Tooth1	60414	13890	SOLID92
	Enamel	Tooth2	62535	14340	SOLID92
	Bone	Jaw	114821	66158	SOLID92
	Stainless steel	Device	13705	6218	SOLID92
	Total		251475	100606	

Table 2: Finite element summary of model without the device, the models with all the three devices.

Space-maintainers	Band and loop	Nance appliance	Trans-palatal arch	Without Device
Range of von mises stresses(pa)	1.8502e-10to 1.5177e8	12.194to 1.989e8	11.862 to 1.8498e8	16.908 to 6.8088e7
Range of strain(m/m)	0 to 0.0030291	8.1293e-10to 0.003271	7.9082e-10to 0.0033436	1.1272e-9 to 0.0035836
Range of deformation(m)	0 to 4.6292e-6	0 to 3.7612e-6	0 to 3.7666e-6	0 to 4.9676e-6

Table 3: Comparison of stresses, strains and deformation of all three designs and jaw.

primary maxillary first molar and suggested that if palatal movement appears to be needed, the dentist should consider use of a palatal arch rather than a band-and-loop maintainer. Yilmaz et al. [9] studied the clinical performance of fixed space maintainers placed on seriously damaged abutment teeth. The study shows the effectiveness of fixed space maintainers combined with stainless steel crowns ("open-face fixed space maintainers") which were placed on primary molar teeth used as abutments in cases with extensive caries and loss of occlusogingival dimension. Traditionally, the treatment of choice for maxillary loss is the placement of a Nance appliance. An alternative appliance which may be considered for use is the Trans Palatal arch or bar [10].

Hence in different clinical situations the primary choice of the space maintainer differs but at the same time whenever possible the appliances those create lesser deformation on the jaw bone should be selected. In our study, we have used the geometrical 3D models rather than directly copying the anatomical 3D CT Scans.

Conclusion

The Nance-appliance shows the lesser deformation than band and loop and trans-palatal arch. This model can be preferred where the stresses developed by the space-maintainers are critical provided the appliance is indicated in the clinical situation. Further, this methodology could facilitate optimization and understanding of biomedical devices prior to animal and human clinical trials.

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References

1. Bijoor RR, Kohli K (2005) Contemporary space maintenance for the pediatric patient. *N Y State Dent J* 71: 32-35.
2. Simon T, Nwabueze I, Oueis H, Stenger J (2012) Space maintenance in the primary and mixed dentitions. *J Mich Dent Assoc* 94: 38-40.
3. Barbería E, Lucavechi T, Cárdenas D, Maroto M (2006) Free-end space maintainers: design, utilization and advantages. *J Clin Pediatr Dent* 31: 5-8.
4. Uddanwadiker RV, Padole PM, Arya H (2007) Effect of variation of root post in different layers of tooth: linear vs. non linear finite element stress analysis. *J Biosci Bioeng* 104: 363-370.
5. Moore TR, Kennedy DB (2006) Bilateral space maintainers: a 7-year retrospective study from private practice. *Pediatr Dent* 28: 499-505.
6. Fathian M, Kennedy DB, Nouri MR (2007) Laboratory-made space maintainers: a 7-year retrospective study from private pediatric dental practice. *Pediatr Dent* 29: 500-506.
7. Tulunoglu O, Ulusu T, Genç Y (2005) An evaluation of survival of space maintainers: a six-year follow-up study. *J Contemp Dent Pract* 6: 74-84.
8. Lin YT, Lin WH, Lin YT (2007) Immediate and six-month space changes after premature loss of a primary maxillary first molar. *J Am Dent Assoc* 138: 362-368.
9. Yilmaz Y, Kocogullari ME, Belduz N (2006) Fixed space maintainers combined with open-face stainless steel crowns. *J Contemp Dent Pract* 7: 95-103.
10. Kupietzky A, Tal E (2007) The Transpalatal Arch: An Alternative to the Nance Appliance for Space Maintenance *Pediatr Dent* 29: 235-238.