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ORIGINAL RESEARCH

Tissue Resistance to Soft Tissue Emphysema during Minimally Invasive Periodontal Surgery

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ABSTRACT

Aim: The aim of this study was to determine the pressure where oral soft tissue resistance will be overcome resulting in soft tissue emphysema and to measure the safety of an antifouling device for a videoscope used during minimally invasive periodontal surgery.

Materials and methods: Resistance was measured *in vitro* in porcine tissue. One study arm measured palatal tissue resistance to air applied through a needle. Another arm measured resistance in a surgical access for minimally invasive periodontal surgery (MIS). India ink was placed on the tissue, pressure at 0,3,10,15,20, and 25 pounds/square inch (psi) applied, and penetration of India ink into the tissue was measured. Three trials in three sites were performed at each pressure in both arms of the study.

Results: Pressure applied to palatal tissue through a needle showed no significant penetration of India ink until 15 psi (0.90 ± 0.24 mm, $p = 0.008$). Penetration considered clinically significant was noted at 20 and 25 psi (4 to 6 mm, $p \leq 0.0001$). No significant penetration was noted in minimally invasive incisions.

Conclusion: Within the test system, pressures of 15 psi or less seem unlikely to cause soft tissue emphysema. No evidence of tissue emphysema was noted with the videoscope antifouling device.

Clinical significance: The use of pressures greater than 15 pounds per square inch should be avoided during surgical procedures. The antifouling device for a videoscope appears safe for use during minimally invasive periodontal surgery.

Keywords: Soft tissue emphysema, Minimally invasive procedures, Periodontics, Surgical procedures, Air compressed.

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INTRODUCTION

Soft tissue emphysema is the presence of air or gas in soft tissue. This can occur spontaneously, be secondary to trauma, or may occur during a surgical procedure where a pressurized gas is used. Knott originally described mediastinal associated soft tissue emphysema as a 'crackling sound' in the chest wall of a patient who had severe coughing.[1] This would be an example of spontaneous soft tissue emphysema. Soft tissue emphysema has also been described to occur following trauma, such as gunshot wounds, stab wounds, and auto accidents.[2-5] The method of air or gas getting into the soft tissue following trauma is usually attributed to a direct blow to the body that forces air into the tissue, such as might occur during an auto accident or traumatic damage to the chest cavity that allows respiratory air pressure to be forced into the tissue.

Dental soft tissue emphysema has been reported under various circumstances. In an early report, soft tissue emphysema was described occurring in a bugler who was said to have forced air into the tissue of the face through the socket of a recently extracted tooth.[6] The most frequently reported occurrence of soft tissue emphysema in dentistry follows the use of an air or gas driven handpiece during surgical procedures.[7-10] Soft tissue emphysema has been reported following third molar extraction, periodontal osseous surgery, and other oral surgery procedures.[11,12]

Published reports of dental soft tissue emphysema have usually been in the form of case reports or case series. Typically, the surgeon will describe the occurrence of soft tissue emphysema and report on the symptoms, treatment, and outcomes. Most cases involve a gas or air driven handpiece that has been used in a relatively deep soft tissue surgical area. The surgeon, and sometimes the patient, may note a sudden distention of the soft tissue. It is theorized that the air or gas from the handpiece overcomes tissue resistance, enters a soft tissue space adjacent to the surgical site, and the pressurized air or gas will inflate the soft tissue (fascial) space. Surgically induced dental soft tissue emphysema will often remain in place for several days until

the gas is absorbed by the body or it escapes naturally. Fortunately, most cases of dentally related soft tissue emphysema do not result in serious patient complications. There have been rare instances of serious complications associated with dental soft tissue emphysema.[11,12]

While the existence of soft tissue emphysema following dental surgery has been reported numerous times, there has not been a study to determine at what pressure air or gas will overcome the resistance of the tissue and allow soft tissue emphysema to occur. A search of the dental literature yielded no studies that looked at the important issue of tissue resistance to air or gas pressure or investigated at what pressure the resistance of the soft tissue would be overcome.

In the application of a videoscope to minimally invasive periodontal regenerative surgery, a major obstacle is that the optics of the videoscope becomes fouled with blood, tissue, and fluid spray from the surgical field. This clinical difficulty has made the use of endoscopes and videoscopes impractical for most dental surgical procedures. An antifogging/antifouling device has been developed for use with an endoscope or videoscope that overcomes this problem by passing a column of air or gas over the optics of the videoscope and thereby shielding the optics and preventing fogging and fouling of the optics (Fig. 1). This allows the surgeon to place the videoscope directly in the surgical field for extended periods of time without the problem of obscuring the optics (Fig. 2).

Some concern has been expressed that when the antifouling device is placed in an enclosed surgical space, such as is the case with minimally invasive surgery, the air flowing around the videoscope might result in soft tissue emphysema. Thus, the purpose of this study is to determine at what pressure the resistance of oral tissue within a minimally invasive surgical incision may be overcome and possibly result in soft tissue emphysema.

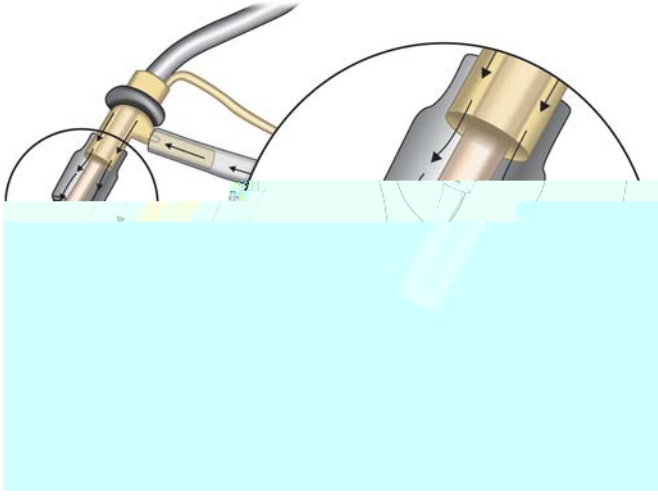


Fig. 1: Schematic drawing of a flexible videoscope with the antifogging and antifouling device attached. The videoscope optics are slightly recessed within a tube that has air or gas (arrows) circulating around the end of the videoscope. The turbulent air in front of the videoscope prevents blood and debris from fouling the optics of the videoscope

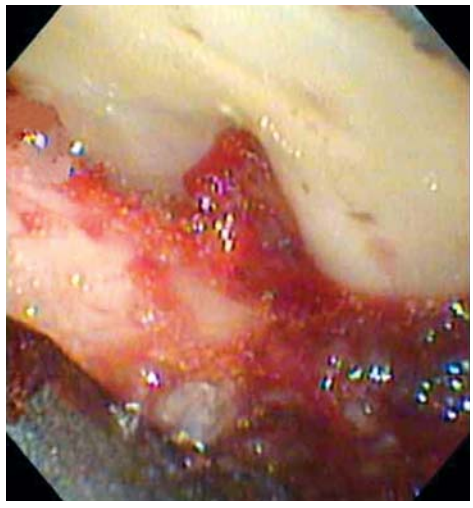


Fig. 2: View through the videoscope of a periodontal defect prepared for regenerative procedures, where minimally invasive incisions 2 to 4 mm in length have been used for access. The antifouling device allows the use of the videoscope without fouling or fogging of the optics

MATERIALS AND METHODS

Because Ethical and Institutional Review Board constraints prohibited the use of human tissue, all studies were performed using oral tissues from fresh pig heads obtained from a slaughterhouse. Two arms of the study were performed. The first was aimed at determining at what pressure the resistance of the tissue of the palate would breakdown and allow India ink to penetrate directly into the tissue. The second looked at the breakdown of tissue resistance within an incision several millimeters into connective, tissue similar to that used for minimally invasive periodontal surgery. In all testing a solution of India ink was used as a marker to indicate the breakdown of the soft tissue resistance to increasing levels of air pressure.[13] Measurements of the penetration of India ink into the tissues were made at atmospheric pressure (control) and at increased levels of air pressure. The distance that the ink penetrated into the tissue under atmospheric pressure was considered to represent the movement of the ink resulting from capillary action and the natural infusion of fluid into the tissue without any external pressure being applied. For each arm of the study the distance the ink penetrated under atmospheric pressure was considered the control tissue penetration.

Since, during minimally invasive periodontal surgery the incisions are limited to interproximal gingival tissues (free and attached gingiva, periodontal ligament and alveolar bone) and incisions are not extended into adjacent mucosal tissue,[14,15] it was decided that initial testing for tissue

resistance to pressure was best performed in pig palatal tissue. The resistance of palatal tissue to penetration of the ink was tested by inserting a 23 gauge butterfly needle into the palatal tissue. Prior to insertion of the needle into the tissue, a valve was placed on the tubing opposite the needle and the vinyl tubing attached to the needle was filled with India ink solution. The valve was closed to prevent the ink from running out of the needle and tubing. The needle was wiped clean of all traces of ink with a saline soaked gauze and then inserted 10 mm into the palatal tissue. The 'wings' of the butterfly needle were attached to the palatal tissue with cyanoacrylate to prevent movement of the needle within the tissue. For each test either atmospheric pressure or compressed air was applied through the needle to the palatal tissue for 1 minute by opening the valve. The 1 minute interval was used to represent the longest continuous time that the videoscope would likely be used at a single site during minimally invasive periodontal surgery. After applying the appropriate pressure for 1 minute, the valve was closed and the compressed air was removed from the valve. The valve was opened again briefly to relieve any residual pressure on the India ink solution. The external needle insertion site was irrigated with normal saline for 1 minute to remove any ink on the surface of the tissue. Following surface irrigation of the tissue, an incision was made into the tissue along the insertion pathway of the needle using a 15c blade. When the tip of the needle was visualized a lateral incision at 90° to the insertion path was made at the needle tip to allow for visualization and measurement of the movement of ink into the tissue beyond the needle tip. Measurements were made under a dissecting microscope using a digital micrometer accurate to 0.01 mm.

Measurement of the resistance of tissue to penetration of the ink solution within minimally invasive surgical sites was performed by creating minimally invasive access incisions between two teeth. Incisions of approximately 3 mm were made on the buccal and lingual aspect and the intervening gingival tissue was removed to the crest of the interproximal bone. The design of minimally invasive surgical incisions has been previously described in the literature.[14,15] The minimally invasive surgical site was filled with 0.2 ml of India ink solution. A videoscope with the antifouling device attached was then inserted into the surgical site (Fig. 3). Atmospheric and increasing levels of air pressure were applied to the antifouling device for one minute. The videoscope and antifouling device were removed and the surgical site was irrigated with normal saline for 1 minute. Following irrigation, a vertical incision was made at the midbuccal and midlingual aspect of the surgical site. The penetration of the India ink into the tissue beyond the alveolar crest was visualized with the dissecting microscope and measurements were made using the digital micrometer.

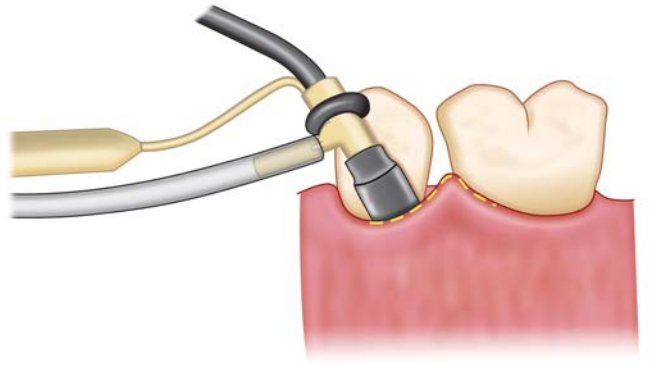


Fig. 3: Incisions for minimally invasive periodontal surgery (MIS) with the videoscope and antifouling device inserted to allow for visualization of the periodontal defect

Control tests were performed by applying atmospheric pressure (i.e. no externally applied air pressure) for 1 minute to either the needle or the minimally invasive surgical sites. Air pressure was applied to the needle or surgical site by attaching a calibrated source of compressed air to the needle tubing or the antifouling device attached to the videoscope. With the needle in the palate, the pressure was applied directly to the valve attached to the needle tubing. With the antifouling device the compressed air was allowed to flow around the videoscope at the preselected air pressure. In all instances the air pressure was applied for 1 minute. The air pressures used were 0 (atmospheric pressure/control) +3, +10, +15, +20 and +25 pounds per square inch (psi) or in kilopascals (kPa): 20.68, 34.47, 68.95, 103.42, 137.9 and 172.37. The +3 psi pressure is the level routinely used during clinical surgical use of the videoscope antifouling device. All tests at each interval of pressure were repeated three times in three separate sites.

Student's t-tests were conducted to determine, if the distance of ink penetration was significantly different between the control and test groups.

RESULTS

The results for tissue penetration of ink when pressure was applied to the palatal tissue through a needle are shown in Table 1. As the pressure was increased, minimal penetration of the India ink into the tissue was observed until the +20 psi level at which point penetration of 4 mm was noted. At +25 psi penetration of at least 6 mm was noted. The 6 mm measurement was the limit of the incision into the palate. At +25 psi the India ink penetrated the entire side of the palate.

Student's t-tests yielded significant differences at the 0.05 level for +15, +20 and +25 psi after controlling the effects of multiple comparisons with Dunnett's corrections.

Table 1: Mean penetration of India ink into palatal tissue from air pressure applied to a 23 gauge needle. Pressure of 15 pounds per square inch (103.42 kPa) or less did not cause a clinically significant amount of tissue penetration

Air pressure	*Mean tissue penetration of ink (mm)*	*p-value*
Control (atmospheric pressure)	0.15 ± 0.30	
3 psi (20.68 kPa)	0.39 ± 0.16	0.215
10 psi (68.95 kPa)	0.60 ± 0.08	0.028
15 psi (103.42 kPa)	0.90 ± 0.24	0.008*
20 psi (137.9 kPa)	4.03 ± 0.74	<0.0001*
25 psi (172.37 kPa)	6.00 ± 0	<0.0001*

*Statistically significant (student's t-test);
Clinically significant (3 mm or greater of tissue penetration)

Table 2: Mean penetration of tissue in periodontal minimally invasive incisions from the videoscope antifouling device. No significant amount of tissue penetration was noted at any of the pressures tested

Air pressure	*Mean tissue penetration of ink (mm)*	*p-value*
Control (atmospheric pressure)	0.00	
3 psi (20.68 kPa)	0.00	N/A
10 psi (68.95 kPa)	0.00	N/A
15 psi (103.42 kPa)	0.00	N/A
20 psi (137.9 kPa)	0.25 ± 0.20	0.182
25 psi (172.37 kPa)	0.13 ± 0.14	0.182

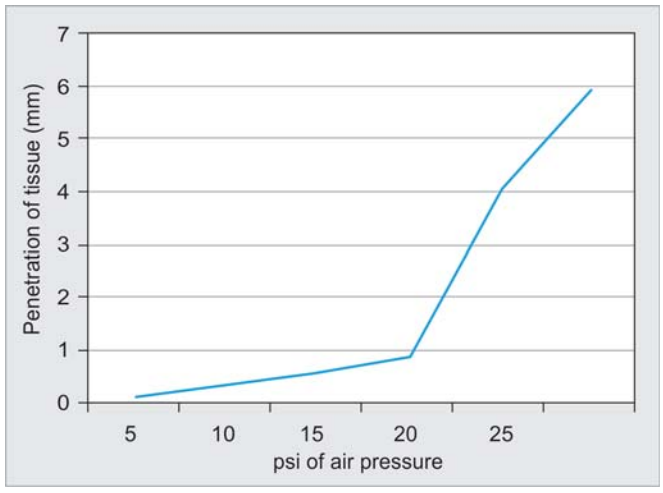
No statistical significance differences achieved (student's t-test)

In order to established an estimate of a 'clinically significant' risk of tissue emphysema, in consultation with the statistician prior to performing any of the tests it was projected that a movement of greater than 3 to 5 mm into the tissue would need to be demonstrated. Based on this assumption, a clinically meaningful statistical significance was achieved at +20 and +25 psi.

The results for the pressure applied to the minimally invasive surgical access incisions are shown in Table 2. In no instance was the tissue penetration greater than 0.25 mm. This tissue penetration distance was not statistically significant at the 0.05 level.

DISCUSSION

The tests on the palatal tissue using the needle placed in to the tissue were designed to determine the pressure where the tissue resistance to pressure would breakdown and the potential for soft tissue emphysema might occur. The results appear to show that palatal tissue can resist the penetration of pressure at or below +15 psi. Once +25 psi was reached, the resistance of the tissue to penetration appears to have broken down completely. The failure of the tissue to resist pressures of +25 psi was sudden and catastrophic (Graph 1). At +10 psi, there was no clinically visible penetration of



Graph 1: Tissue penetration related to psi of air pressure applied to a 23 gauge needle in the palatal tissue. Minimal tissue penetration is noted at +15 psi (103 kPa) and below. Tissue resistance to air pressure appears to breakdown rapidly at pressures above +15 psi

the tissue by the ink and minimal penetration of the tissue noted when the area was incised. When the air pressure was increased to +25 psi, there was clinically observable rapid breakdown of tissue resistance with India ink observed coloring the tissue for several centimeters around the needle. Ink was observed flowing out along the midline and apparently flowing out from the openings of minor salivary glands in the palate. The results of this arm of the study appears to show that within the tissue studied, pressures up to +15 psi (103 kPa) are probably safe to use while pressures above +15 psi represent a risk for tissue penetration and therefore a risk for soft tissue emphysema.

The results of the tests in the minimally invasive surgical sites appear to indicate that there was no ink being forced into the tissue even at the high end of the test pressures (+25 psi). The lack of penetration of India ink into the tissue resulting from the pressures applied through the videoscope antifouling device appears to show that the there is little danger of air emphysema from the use of this device at pressures up to the upper limit of testing.

It should be pointed out that the pressure applied to the tissue at the end of the 23 gauge needle is applied in a tightly closed environment. While undoubtedly some pressure is lost from the tissue around the shaft of the needle, minimal to no India ink was observed around the needle shaft when the incisions were made. This means that a small cross-section of tissue was placed under full pressure for the full minute of the test. Despite the unlikely nature that these conditions would be encountered during routine surgery, it appears that pressures of +20 psi (138 kPa) or higher in tightly closed environments represent a risk for tissue penetration and should be avoided. An example of where

this might occur would be the insertion of a tube or air-water syringe tip into a small surgical area for irrigation or the forcing of air or liquid into an endodontic access opening.[16,17]

It also should be pointed out that palatal tissue is not an area where soft tissue emphysema commonly occurs. Soft tissue emphysema is frequently reported in areas of mucosal tissue flaps such a third molar extraction sites. However, palatal tissue most close resembles the interproximal tissue encountered where minimally invasive surgery is usually performed. Additionally, palatal tissue is believed to be a good test area for determining the maximum resistance of oral tissue to external air pressure.

In the second arm of the study, the results from applying pressure to the minimally invasive surgical site via the antifouling device appear to indicate that high air pressure applied in a nonenclosed environment is relatively safe. In practice, the videoscope is routinely placed 1 to 2 mm above the surface of the tissue to allow for adequate visualization of the surgical site. By not placing the air pressure directly on the tissue the air flowing around the videoscope has a chance to escape to the atmosphere and because of this would not place full pressure on the tissue. Further, the air pressure routinely used clinically with the videoscope antifouling device is quite low at +3 psi (21 kPa). Therefore, it appears that the routine use of the videoscope antifouling device does not represent a risk for air emphysema.

Some caution should be used in applying the results of this study beyond the instruments tested and the system used to test them. First, the tissue studied was fresh but not living. It is unknown whether living tissue would be more or less resistant to air pressure. Logic would seem to indicate that living tissue may be more resistant to air pressure but that cannot be determined from the results of this study. Second, the tissue studied was not human. It is unknown, if pig tissue might be more or less resistant to air pressure than human tissue. Inquires were made at two institutions and permission for the use of human tissue for this study was withheld. Ethical considerations make it very unlikely that tissue resistance in human tissue could be studied in the manner used in the current study. Third, this study looked at the resistance of tissue to pressure. It did not look at the resistance to pressure between tissue spaces, such as the fascial spaces that may be encountered in some surgeries such as third molar extractions.

CONCLUSION

To our knowledge this is the first study that has looked at the resistance of tissue to air emphysema. This study seems to indicate that pressures within a closed space of +15 psi (103 kPa) or less are unlikely to cause tissue emphysema while pressures above this may represent a danger for soft tissue emphysema. The results from the study of the antifouling device for the videoscope appear to indicate that there is less danger of emphysema, if pressure is not placed on tissue in a closed environment. In other words, greater pressure can probably be safely applied to oral tissue in a situation where it is possible for the air to escape to the atmosphere. Most oral surgery procedures do not require that pressure above +15 psi (103 kPa) be applied to tissue in enclosed spaces. The risk of tissue emphysema represented by the judicial use of pressure at or below +15 psi (103 kPa) appears to be minimal.

CLINICAL SIGNIFICANCE

Within the limits of the test system used, the risk of soft tissue emphysema during oral surgery procedures appears to be minimal when a pressure of +15 psi (103 kPa) or less is used. The risk of air emphysema from the use of the antifouling device for the videoscope when used in minimally invasive incisions and at the routinely used pressure of +3 psi (21 kPa) also appears to be minimal.

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